Chapter 36

The Ontogeny of Taste Perception and Preference Throughout Childhood

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36.1 INTRODUCTION

The study of the ontogeny of human taste perception has been the focus of scientific investigations for more than a century (as summarized in Table 36.1). From this knowledge base, we now know that humans are born with a well-developed peripheral taste system—a taste system that, by the last trimester of pregnancy, is capable of conveying information to the central nervous system. This information is made available to brain structures critical for organizing a variety of consummatory (e.g., intake) and reflex-like (e.g., facial expressions) behaviors; (see Ganchrow and Mennella, 2003, for an earlier review). Clearly, taste plays an important role in determining whether a foreign substance should be accepted or rejected, and informs the gastrointestinal system about the quality and quantity of the impending rush of nutrients (Egan and Margolskee, 2008; Sclafani, 2007). Although the taste system involves innate responses, these responses change and mature throughout childhood, as will be described in this chapter (e.g., Cowart, 1981; Mennella et al., 2010b; Stein et al., 1994).

The sense of taste has taken on great interest in recent years because it is a major determinant of the food acceptance patterns of children (Birch 1998). Thus, our accumulating knowledge about taste plays an important role in understanding the basis for food choices in children. Although the modernization and industrialization of the food supply have produced many benefits, diets rich in sugars and salt and low in fruits and vegetables have become increasingly commonplace, thereby producing unanticipated consequences. For example, excessive intake of foods containing high amounts of salt or sugars (and, consequently, foods that taste salty and sweet) causes or exacerbates a number of illnesses, including hypertension, diabetes, and metabolic syndrome (Mokdad et al., 2004). Reduced intake of fruits and vegetables increases the risk of a number of chronic diseases, including cardiovascular diseases and certain cancers (Knai et al. 2006). Because eating vegetables as part of an overall healthy diet can aid in weight management for children and adults (Blanck et al., 2008; Lakkakula et al., 2008; McCrory et al., 1999), their reduced intake likely contributes to the obesity epidemic.

In this chapter, we focus on the approaches and discoveries that have contributed to our current knowledge of human development of the five "basic" tastes of sweet, sour, salty, bitter, and umami (savory) and the impact they have had on our understanding of the sensory world of children. This review is not meant to be representative of all research conducted to date; rather, it highlights the breadth of methodologies employed, the convergence of findings, and extant gaps in knowledge. Although a detailed treatment of taste anatomy is beyond the scope of this article, we begin by providing an overview of the mechanisms underlying taste sensations and when they emerge during development.

36.2 THE ONTOGENY OF TASTE PERCEPTION

Taste, or *gustation*, refers to the sensation that occurs when chemicals stimulate taste receptors located on a

large portion of the tongue's dorsum and other parts of the oropharynx, such as the larynx, pharynx, and epiglottis. *Flavor,* in contrast, is elicited by a combination of tastes and odors experienced orthonasally and retronasally while consuming substances. Taste is initiated at taste receptors, which are localized in taste buds and are innervated by branches of three cranial nerves: the facial (VIIth), glossopharyngeal (IXth), and vagal (Xth) nerves. The taste stimuli that interact with these receptors are often separated into a small number of "primary" taste qualities: sweet, salty, bitter, sour, and umami.

Contemporary knowledge about the development of the five basic taste qualities stems from research that has examined receptor morphogenesis and functional maturity (for review, see Bradley and Mistretta, 1975; Cowart et al., 2004; Ganchrow and Mennella, 2003). Early research conducted in this ~~area, which focused on investigating when the taste system becomes functional and its subsequent pattern of development throughout childhood,~~ revealed that taste buds begin to emerge throughout the oral cavity, including the dorsal surface of the tongue, palatoglossal arches, palate, posterior surface of the epiglottis, and posterior wall of the oropharynx, just 8 weeks after conception. By 13 weeks, taste buds begin to resemble those of the adult and are found throughout the oral cavity (Bradley and Mistretta, 1975; Bradley and Stern, 1967; Hersch and Ganchrow, 1980; Witt and Reutter, 1996; 1998). Taste pores, which provide access for tastants to interact with taste bud receptor cells, are generally considered as markers of functional maturity (Mistretta, 1972). Such pores have been identified in fetal fungiform papillae before the end of the fourth month (Witt and Reutter, 1996; 1998). At birth, the newborn infant is endowed with a rich population of gustatory receptors associated with such pores.

It is probably not a coincidence that the timing of these developmental changes corresponds to the emergence of fetal sucking and swallowing behavior. Ultrasound studies have revealed early development of swallowing and oral sensorimotor function at approximately 15 weeks gestational age (Miller et al., 2003; Ross and Nijland, 1997). By term, infants are actively swallowing between 500 and 1000 ml/day of amniotic fluid (Pritchard, 1965; Ross and Nijland, 1997). This not only represents a major route of amniotic fluid absorption but also serves to stimulate the taste buds and influence their synaptic connections. The chemosensory composition of the amniotic fluid is constant flux throughout pregnancy, especially once the fetus begins to urinate, exposing the newly developed taste buds to varying concentrations of a variety of chemicals, including sugars, sodium and potassium salts, various acids (Liley, 1972), and flavors from the mother's diet (Mennella et al., 1995).

36.3   RESEARCH APPROACHES AND METHODOLOGIES

Table 36.1 presents an extensive summary of studies of taste sensitivity and preference during development, organized by taste quality, age group, and methodology. A variety of psychophysical methodologies have been employed to assess taste perception and preference throughout infancy, childhood, and adolescence. The method chosen depends on the objective of the study as well as the age (and, in turn, cognitive and language abilities) of the participants under study. These psychophysical studies on taste provide data relevant to two separate aspects of sensation: (1) the *sensitivity* of the system to chemical stimuli and (2) the *hedonic valence*, or pleasantness, of the sensation (Cowart, 1981; Cowart et al., 2004).

For preverbal children, the tools used often focus on reflex-like responses (e.g., salivation, sucking, heart rate, or orofacial responses) or consummatory responses. Interestingly, many of the experimental paradigms for this age group are similar to those used in animal studies (Berridge and Kringelbach, 2008; Boughter and Bachmanov, 2007; Glendinning et al., 2002; Grill and Norgren, 1978; Spector et al., 1981; Steiner et al., 2001). Because virtually all of these measures can be associated with acceptance or rejection, they presumably involve a hedonic component. As a result, sensitivity and hedonics are difficult to distinguish in animals and in nonverbal infants (Cowart et al., 2004).

For older children, a variety of methodological tools have been used, which vary according to their language and cognitive development. Measures of sensitivity include threshold detection, suprathreshold scaling procedures; hedonic measurements include ratings or ranking of stimuli. Several of these sensory methodological tools have been published in standard guides (ASTM International, 2003) and review articles (Popper and Kroll, 2005) and often are modifications of methods used in adult populations. However, the validity and reproducibility of many of these procedures have not been assessed for children.

Findings from this expanding collection of methodological tools are remarkably consistent across studies and laboratories throughout the world. In the sections that follow, we review the methodologies used with children of different ages and highlight findings that support the hypothesis that behaviors associated with gustatory function are robust during early development and contribute significantly to adaptation and survival of the developing infant and child.

36.4   TASTE SENSITIVITY IN THE FETUS

A key question in the ontogeny of taste perception is whether function is present prior to birth. As summarized in Table 36.1, two approaches have been used to answer this important question: (1) indirect observations of the fetus and (2) direct observations of premature infants. Although the response of human fetuses to taste has never been directly investigated, indirect evidence from studies in fetuses together with findings from studies in premature infants, suggests that prenatal monitoring of some taste stimuli is possible during late gestation. Moreover, as alluded to earlier in the chapter, the fetus is exposed to a unique chemosensory environment prior to birth (for review, see (Mennella, 2007).

There are two reports of increased fetal swallowing following the injection of sweet stimuli such as saccharin into the amniotic fluid of pregnant women (DeSnoo, 1937; Liley, 1972), Decreased swallowing has been noted following analogous injection of bitter-tasting poppy seed oil (Liley, 1972). Such findings provide indirect evidence that the fetus is capable of tasting and differentially responding to bitter- and sweet-tasting substances.

Stronger evidence that the fetus can respond to taste stimuli comes from research on premature infants. To overcome methodological limitations caused by premature infants' immature suck-swallow coordination, innovative methods have been developed that avoid the risk of fluid aspiration. These include brief, intermittent presentations of small quantities of tastants (sometimes on absorbent cotton) directly into the oral cavity (Eckstein, 1927; Tatzer et al., 1985) and embedding tastants in a nipple-shaped gelatin media that release small amounts of tastants during mouthing or sucking (Maone et al., 1990). By measuring the strength, length, and latency of nonnutritive sucking to these tastants relative to a control, such as water, researchers have been able to infer sensitivity to, and preferences for, various tastants. This body of research revealed that newborns delivered preterm and tested postnatally produced stronger and more frequent sucking responses when offered a sucrose-sweetened nipple compared to an unsweetened gelatin-based nipple (Maone, Mattes et al., 1990), or to drops of sweetened solution compared to water (Tatzer, Schubert et al., 1985).

When small amounts of bitter or sour tastants were placed directly on the tongue of preterm infants, differential responding has been observed Eckstein (1927) found, for example, that various concentrations of bitter-tasting quinine retarded sucking in most of the infants he studied, whereas a drop of pure lemon juice increased reflex salivation that was accompanied by increases in sucking vigor

and, in some cases, retching. Taken together, this body of research suggests that by the last trimester, humans have a well-developed taste system capable of detecting and hedonically responding to sweet, bitter, and sour tastants.

36.5   TASTE SENSITIVITY AND PREFERENCE DURING INFANCY

36.5.1   Sucking and Consummatory Responses

Sucking and ingestive responses have been successfully used to study patterns of responses that occur as a function of individual and age-related differences in taste perception and preferences throughout infancy (summarized in Table 36.1). Methods include delivering small quantities of taste solutions (1–2 ml) applied directly to the tongue (Crook and Lipsitt, 1976; Crook, 1978), embedding tastants in a gelatin-based nipple (Maone et al., 1990), or providing brief (30–180 s) access to multiple bottles in succession which contain various taste or diluent solutions (Beauchamp et al., 1994; Beauchamp et al., 1986; Beauchamp and Moran, 1982; Beauchamp and Pearson, 1991; Kajuira et al., 1992). One can infer that the infant can detect the tastes, and to some extent that they prefer the taste solution (e.g., sweetened water) more than the diluent (e.g., water), if they consume more from the bottles that contain the taste solution than from those that contain the diluent solution (Beauchamp et al., 1986; Desor et al., 1973). Consistent with the findings for premature infants, research has repeatedly demonstrated strong acceptance of sweet-tasting sugars by the newborn. Within days after birth, they can not only detect dilute sweet solutions, but can also differentiate varying degrees of sweetness and different kinds of sugars (Desor et al., 1973). These findings converge with physiological findings that sweet tasting stimuli administered to newborn infants produced greater relative left-sided activation in both frontal and parietal regions of the brain, which is considered to be a reliable indicator of positive emotion (Fox and Davidson, 1986).

The early studies of Desor, Maller, and colleagues (Desor et al., 1975; Maller and Desor, 1973) found that newborns did not differentially consume bitter and sour solutions relative to water. Thus, it was not clear whether newborns failed to detect the taste solution or were indifferent to it. This conundrum was overcome by the adding sugar to the diluent making it slightly sweet (0.07 M), raising its baseline ingestion above that of water, which is typically aversive to newborns. When citric acid was added to this weak sweet diluent, consumption of the solution was reduced, indicating that the citric acid could be detected

and was aversive (Desor, Maller et al., 1975). However, they did not differentially consume a urea solution, which has a bitter taste. According to a later study, differential consumption of urea does not occur until infants are approximately 2 weeks of age, at which point they began to reduce their consumption of urea in a sweetened solution relative to the sweet diluent alone (Kajuira et al., 1992).

Another example of the importance of employing an appropriate diluent for taste testing in infants can be found in the research on umami taste. The early work of Steiner (1987) revealed that babies reject umami taste (e.g., amino acid L-glutamate, 5′-ribonucleotides) in water, presumably because the addition of glutamate decreases the palatability of water solutions. However, because glutamate tends to increase the palatability of food, more recent research with infants used the same method as for older children and adults, by providing the umami taste in a soup broth (Beauchamp and Pearson, 1991; Steiner, 1987; Vazquez et al., 1982) or an infant cereal base (Mennella et al., 2009). When the umami taste was presented in these food bases, infants exhibited differential preference for umami by consuming more when glutamate was added to the diluent.

A further methodological consideration for consummatory studies is that failure to control for basic stimuli (e.g., concentration, temperature, volume, and type of diluent) and methodological parameters (e.g., degree of satiation, experience, and age of the participants) may produce data that are variable and inconsistent. Many of these issues can be resolved by using a within-subject design. Mennella et al., (2009) fed, on different days, a familiar cereal that was adulterated with D-lactose (sweet), sodium chloride (salty), urea (bitter), citric acid (sour), or monosodium glutamate (umami). The presentation order of the cereal preparations was counterbalanced across days. During each test session, which occurred at approximately the same time of day and 30–60 minutes before the next scheduled feeding, mothers fed their infants while wearing a mask and refrained from talking, thereby eliminating potential influences of their facial or verbal responses on the infants' behaviors. Infants determined the pacing and duration of the feeding, and the experimenter, who was out of view of the mother–infant dyad, ended the feeding when the infant rejected the food on at least three consecutive occasions. Results indicated that infants' consumption of the different cereals was determined to some extent by their early feeding experiences: infants who had been fed protein hydrolysate formula (a formula that tastes bitter, savory and sour due to high levels of free amino acids) ate significantly more savory, bitter, sour, and plain cereals than did those who had been breastfed or formula-fed, and in formula-fed infants who were eating table foods, intake of the cereals with each of the basic tastes reflected the types of foods they had been fed. Thus, when grouping participants for data analyses, it is important to consider their early feeding history so that differences in taste preferences will not be masked by experience-related factors.

To what extent do early experiences alter or modulate the development of sweet preferences later in life? Early feeding patterns have been shown to modulate infants' innate preference for sweet tastes. Longitudinal studies have found that babies who were routinely fed sweetened water during the first months of life exhibited a greater preference for sweetened water during brief-access tests when tested at 6 months and then again at 2 years of age (Beauchamp and Moran, 1984; 1982) compared to those who had little or no experience with sweetened water. A more recent cross-sectional study of 6- to 10-year-old children supported these findings and revealed that such feeding practices may have longer term effects on the preference for sweetened water than previously realized (Pepino and Mennella, 2005b).

For salt, the story is more complex. Unlike innate responses to the other basic tastes, differential responses to salt are not exhibited by newborns. Rather, responsivity matures postnatally. While infants younger than 4 months of age consumed moderate concentrations of salt solution (0.10–0.20 M) and water in equal amounts, those between 4 and 24 months of age consumed more of the salt solutions relative to water (Beauchamp et al., 1986; Desor et al., 1975b). Beauchamp and colleagues have argued that postnatal experience with salty tastes probably does not play a major role in this shift from apparent indifference to salt at birth to acceptance at 4 months of age, ~~which,~~ instead may reflect postnatal maturation of central or peripheral mechanisms that underlie salt taste perception (Beauchamp and Cowart, 1985; Cowart and Beauchamp, 1990). Later research has demonstrated that infants younger than 4 months of age may not be completely indifferent to salt taste. When presented with moderate (0.17 M) and strong (0.34 M) concentrations of a salted solution relative to water at 2 months of age, they consumed significantly less of the strong salt solution relative to water, and their acceptance of both concentrations of salt was negatively associated with their birth weight (Stein, Cowart and Beauchamp, 2006).

Infants' acceptance of salty taste is also affected by prenatal experiences. Infants born to women who reported suffering from moderate to severe symptoms of morning sickness had significantly higher relative intake of salt solutions at 4 months of age than did those whose mothers reported having no more than mild morning sickness (Crystal and Bernstein, 1998). That these effects last beyond infancy is suggested by the finding that adolescents and young adults preferred higher concentrations of salt in a soup base in the laboratory, and reported significantly higher daily salt use, if either they had suffered from infantile vomiting or diarrhea themselves or their mothers had suffered from morning sickness while pregnant with them (Lesham, 1998).

Like experience with sweet, experiences with salt provide the infant with opportunities to learn about the level of saltiness to be expected in foods. As has been observed with sweet taste, 6-month-old infants' consumption of moderate (0.17 M) and strong (0.34 M) salt solutions (Stein et al., 2012) or salted cereals (Harris, Thomas et al., 1990) can be modified by their dietary patterns once they start eating table foods. Relative to those who did not eat starchy foods, which are a significant source of sodium in infants' diets, those who ate these foods at home consumed significantly more of a solution or cereal when salt was added. Thus, it appears that although infants' hedonic responses to basic stimuli are innate, early experiences, some of which ~~occur,~~

36.5.2 Orofacial Expressions

Reflexive orofacial changes of both humans and animals to tastes and flavors have also been widely studied (see Table 36.1) (Berridge and Kringelbach, 2008; Forestell and Mennella, 2012; Grill and Norgren, 1978; Mennella et al., 2009; Spector et al., 1981; Spector and Travers, 2005). Similarities between species in their facial responses to taste stimuli (as reviewed in Berridge, 1996) suggest that such behavioral responsivity has evolved in a range of mammals and is clearly adaptive. It has been hypothesized that the small number of taste qualities evolved because of the functional importance of the perception of basic taste qualities in nutrient selection. Preference for salty, sweet, and savory tastes is thought to have evolved to attract us to that which is beneficial: salty-tasting minerals, energy-producing sugars, and vitamin- and protein-rich foods; in contrast, rejection of bitter-tasting substances may have evolved to protect mammals and other organisms from poisons, many of which are bitter (Glendinning, 1994; Jacobs, 1978).

Steiner (1973) was among the first to examine facial reactivity in detail to tastants in human infants. Evidence supporting the concept that these orofacial responses were innate and unlearned came from observations that they were present in both normal and anencephalic infants whose brainstems were intact within hours of birth and before their first postnatal feeding. In these pioneering studies, a drop of solution representing one of the basic taste qualities (i.e., sweet, sour, salty, bitter) was placed on the infant's tongue. Responses of normal and anencephalic infants were strikingly similar: when tasting sweet, their faces relaxed and they began suckling and smiling; in contrast, bitter tastes elicited gaping responses, while sour elicited squinting and lip pursing (Steiner, 1973, 1977, 1979). No facial response was evident to salt before the age of 4 months, which is consistent with findings from the consumption studies discussed above e.g., (Beauchamp et al., 1986). That normal as well as anencephalic infants demonstrated similar orofacial responses suggests that

these responses are mediated in the region of the hindbrain and not in the cerebral cortex, where voluntary movement is controlled (Steiner, 1973, 1977).

Subsequently, Rosenstein and Oster (1988) employed a more precise method of describing orofacial responses with Ekman and Friesen's anatomically based Facial Action Coding System (FACS; Ekman and Friesen, 1978). ~~By using~~ this system, virtually any facial expression can be dissected into its constituent action units (AUs). In Rosenstein and Oster's study, the percentages of infants who emitted particular reactions, or AUs, to sweet, sour, bitter, and salt solutions were measured. When initially tasting a sweet substance, infants transiently showed negative mid-face actions, such as cheek raising (AU 6) or nose wrinkling (AU 9). This was followed by more positive and sustained responses such as facial relaxation and sucking. In contrast to the observations of Steiner and colleagues (e.g., Ganchrow et al., 1983; Steiner, 1973), this study did not find marked smile-like facial responses to the presentation of sweet tasting stimuli (AU12). In response to sour and bitter tastants, infants reacted more negatively, as demonstrated mainly by their lower-face actions. For example, while both sour and bitter solutions elicited similar upper and midface AUs (which included cheek raises (AU 6)), sour solutions elicited lip pursing (AU 18), and bitter solutions elicited gaping (AU 26 and AU 27). Although no such FACS analysis has been conducted on the newborn's response to umami taste, Steiner (1987) has reported that the presentation of umami-tasting stimuli results in facial relaxation, sucking, and smiling in infants.

In more recent studies, slow-motion video analysis (Berridge, 1996) has been used to quantify the actual number of affective reactions infants express to a taste stimulus as a measure of the valence and intensity of an affective reaction (Mennella et al., 2009). A necessary requirement of this method is the need for trained individuals (preferably certified in FACS) to analyze the video images and establish reliability between their scores, which can be time-consuming and costly. In one study, the number of AUs each infant expressed in response to sweet, sour, bitter, savory, salty, and plain cereal over the first two minutes of each feeding session was recorded (Mennella et al., 2009). Because of marked individual differences in the display of faces, the analyses focused on the total number of facial expressions of distaste made for each spoonful offered, as well as the incidence of specific facial responses such as gapes and smiles. In general, infants made more facial responses related to distaste while eating the bitter cereal than while eating the other cereals. Moreover, those who had been fed protein hydrolysate formula or breast milk, both of which are higher in glutamate content than are formulas based on cow's milk, smiled more when fed the savory cereal than did those fed milk-based formulas. The effects of early exposure to flavors appear to be particularly

persistent, lasting for several years. That is, children who were fed hydrolysate formulas as infants appear to be programmed to like not only the taste of protein hydrolysates but also the taste of foods that are more savory (e.g., chicken), sour (e.g., lemon), and bitter (e.g., broccoli) compared with children who were fed milk-based formulas (Liem and Mennella, 2002; Mennella and Beauchamp, 2002; Mennella et al., 2006; Schuett et al., 1985). These findings provide further evidence of the plasticity of the taste system such that the early diet can determine later preferences and dietary habits.

In summary, studies on orofacial responsivity to taste demonstrate that, like adults, infants can control the muscles required to express primary emotions and are thus well equipped to convey a wide range of emotional states and reactivity to tastes (Ekman and Oster, 1979). Moreover, the ability to discriminate all but one of the basic tastes (salt) is evident early in life, and infants can respond with characteristic facial responses that correspond to the hedonic valence of the taste stimulus. Thus, infants' facial expressions can provide caregivers with important information about whether they like or reject a food (Forestell and Mennella, 2007, 2012). Visually striking facial displays of gaping are readily identified by caregivers and thus provide preverbal infants with an efficient means to communicate their dislike of the taste of what they are eating.

36.5.3 Analgesic Responses

Sucrose acts as an opioid-receptor-dependent calming agent; thus, its ability to act as an analgesic has been the subject of extensive investigations in preterm and term infants, beginning with the early work of Blass and Hoffmeyer (1991). As demonstrated in a recently updated systematic review, Harrison et al., (2010), studies performed over the past 20 years have shown that sweet tastants can be effective in reducing spontaneous crying and pain in preterm and term infants during an array of painful procedures such as a heal lance, venipuncture, or intramuscular injections, with minimal to no side effects. In these studies, crying, and in some cases heart rate/vagal tone, sucking, and facial grimacing, was evaluated before, during, and immediately after infants received a sweetened pacifier or drops (i.e., 0.05–0.5 ml) of nutritive (e.g., sucrose, glucose, or fructose) (for review, see Stevens et al., 2010) or nonnutritive (aspartame; Barr et al., 1999) sweeteners in solutions and compared to responses of infants given unsweetened pacifiers or drops of water, respectively.

This body of research, as summarized in Table 36.1, has revealed that, in general, when a small amount of a sweet substance is placed on the tongue of a crying infant, a rapid, calming effect ensues that persists for several minutes, whereas no such response is observed when water

or an unsweetened pacifier is administered. This reduction in crying is concordant with changes in measures of other physiological reflexes, such as heart rate and orofacial responses. Sucrose has also been shown to attenuate a negative electroencephalographic (EEG) response to a painful procedure (Fernandez et al., 2003), suggesting that sucrose blocks pain afferents, which in turn diminishes stress and cardiac changes. Because noncaloric sweet substances such as aspartame mimic the calming effects of sucrose (Barr et al., 1999), and the administration of sucrose by direct stomach loading is ineffective (Ramenghi et al., 1999), it is generally accepted that afferent signals from the mouth, rather than gastric or metabolic changes, are responsible for the analgesic properties of sweet tastes. Interestingly, such effects may be also induced by some non-sweet tasting stimuli. Thus, one study found that quinine transiently decreased crying (Graillon et al., 1997), implying that in addition to positive hedonic valence, taste salience may account for initial crying reduction. It is presently is unknown whether other tastes, such as salty or sour tasting agents, would produce similar analgesic effects.

36.6 TASTE SENSITIVITY AND PREFERENCE IN CHILDREN

The ability to reliably measure changes in the taste system throughout childhood requires a thorough understanding of developmental abilities of children at various ages so that developmentally appropriate tasks may be chosen after careful consideration of the objectives of the study and the methodological issues. There is a need for more experimental investigations of children's taste sensitivity and preference; however, a major challenge in studying children's behavioral responsivity is to identify developmentally appropriate tasks that are fun for children and that produce reliable and valid results (Mennella and Beauchamp 2008). Below we discuss some of the methodological issues to consider when designing experiments to measure taste sensitivity and preference in 2- to 16-year-old children.

When testing children, care should be taken to create a friendly and inviting atmosphere and to employ an age-appropriate experimental protocol to ensure that both the child and the parent are comfortable with the setting. Upon arrival, initial interactions with the child and parent should be devoted to developing rapport and allowing them to habituate to the testing environment. To encourage the child to engage in the testing procedure, test sessions should not begin with an unpleasant taste. It is also important to remember that children are sensitive to demand characteristics and will often alter their behavior to conform to the experimenter's expectations.

For example, children will often answer questions in the affirmative. This can be avoided by using a forced-choice categorization procedure, which requires that they choose which solution they like better (or is more concentrated), rather than indicating whether they like (or can detect) the taste of a solution. In general, experimental tasks should be embedded in the context of games that are fun for the child and minimize the impact of language and cognitive development.

Relative to older children and adults, young children have difficulties with concept formation (e.g., sweetness) and classification (e.g., like/dislike), and because of their limited linguistic skills, they may have difficulty understanding directions or the abstract nature of symbols and pictures. Therefore, prior to actual testing and after a period of acclimation, the experimenter should ascertain whether or not the child comprehends the task. Even when children understand the task, they are more prone to attention lapses and limited memory spans, which may limit their performance. For example, 3-year-old children can understand a standardized sorting task, but only about half have the attention span to successfully complete the task. Any method relying on sustained attention that places demands on memory could yield spurious findings. For this reason, it is important to establish the reproducibility of measures over time. Unfortunately, few peer-reviewed research studies have systematically determined the validity of their methods among children of varying ages (Chambers, 2005). Moreover, only a handful of studies reviewed herein include methods to assess how reproducible and stable the child's response is over time.

In the following sections, we describe the methodologies used to measure 2- to 16-year-old children's reflex-like behaviors to tastants and the behavioral tasks performed to measure their taste sensitivities and preferences. A summary of this research is provided in Table 36.1.

36.6.1 Reflex-like Behaviors

36.6.1.1 Orofacial Responses. Although studies with infants have used orofacial responses to measure differential responses to the basic tastes (Rosenstein and Oster, 1988; Steiner, 1973, 1977), fewer studies have used this approach to measure hedonic responses in older children. As children mature they learn to control and manage their facial expressions to satisfy display rules that are consistent with societal norms (Ekman and Freisen, 2003; Larochette et al., 2006). Because of such emotional masking, children's attempts to conceal or exaggerate their actual responses to particular tastes may lead to biased or inaccurate data. According to Ekman and Freisen (Ekman and Freisen, 2003), although individuals attempt to manage their facial responses, micro-expressions that reflect their true emotions often "leak" into their overall expression for

a fraction of a second. Although these microexpressions are difficult to measure, subtle changes in facial responses can be detected using facial electromyography, which measures the electrical activity of facial muscles and can detect movements that are too discrete for the eye. This procedure has been used to measure hedonic, emotional, and cognitive responses to tastes (Hu, Luo et al., 2000; Armstrong, Hutchinson et al., 2007; Armstrong et al., 2007; Epstein and Paluch, 1997; Hu et al., 1999, 2000). The three most commonly used muscles for detecting changes with EMG are the levator labii, contraction of which results in lifting of the upper lip (AU10) and wrinkling of the nose (AU9), and the corrugator supercilii, which furrows the brows (AU4). Both of these muscles respond strongly to unpleasant stimuli and poorly to pleasant stimuli. The third muscle is the zygomatic major muscle, which pulls up the corners of the lips (AU12) and responds strongly to hedonically positive and negative taste stimuli (Armstrong et al., 2007). Future research that incorporates the monitoring of facial expressions will provide important insights into children's sensitivity and liking of basic tastes.

36.6.1.2 Analgesic Responses. Only a few published studies have investigated whether the analgesic effect of sweet tastes extends from infancy into later childhood (Miller, Barr et al., 1994; Lewkowski et al., 2003; Pepino and Mennella, 2005b; Mennella, Pepino et al., 2010). In order to induce pain in 8- to 11-year-old children in an ethical manner, these studies have used the cold pressor test in which participants submerge a forearm in a cold water bath (10 degrees Celsius) while holding ~~either~~ equal volumes (15–20 ml) of water or 24% sucrose solution in the mouth.

Such studies have demonstrated that the pain threshold (the time in seconds at which discomfort was first indicated by raising the non-immersed hand) and pain tolerance (the number of seconds the hand was kept in the cold water) are both increased when children hold sucrose, but not water, in the oral cavity (Mennella et al., 2010b; Miller et al., 1994; Pepino and Mennella, 2005b). Interestingly, sucrose's efficacy in reducing pain threshold and tolerance was related to the hedonic value of sweet taste for the child: the more a child liked sucrose, the more tolerant the child was of the pain of the cold water while tasting sucrose (Mennella et al., 2010b; Pepino and Mennella, 2005b). Further work has demonstrated that children who have depressive symptomology report eating more sweet-tasting foods than do those who are not depressed; however, they had similar pain thresholds regardless of whether they held sucrose or water in the mouth during the cold pressor task, demonstrating that sucrose is an ineffective analgesic for these children (Mennella et al., 2010b). Thus, it appears that depression antagonizes the analgesic properties of sucrose.

36.6.2 Behavioral Methodologies for Measuring Taste Sensitivity and Preference

36.6.2.1 Paired-Comparison and/or Forced-Choice Procedures.

In older children, it is possible to use methods that do not confound sensitivity and hedonics. Often these methods involve forced choice, a procedure that requires respondents to compare two or more options and choose one. In taste studies with children, forced-choice procedures often involve the presentation of a series of trials that present solutions that vary in concentration of a particular tastant. Each of the solutions in the series may be presented alone, in which case the children are asked to indicate whether they can detect or like the tastant in each sample. Alternatively, each solution may be paired with another solution (e.g., the diluent, or another concentration of the tastant). In these studies children are asked to compare the solutions on each trial and to choose which they like best (preference), or which contains the tastant under study (sensitivity). In some cases, especially when the subject population consists of children younger than 5 years, this forced-choice task is embedded in the context of a game (Mennella et al., 2005; Schmidt and Beauchamp, 1988) or story (Visser et al., 2000). In general, forced-choice, paired-comparison procedures, unlike tests where the subject is required to remember sequentially presented stimuli to make relative judgments, are especially useful for young children because memory requirements are minimized. Below we highlight some examples of procedures that have utilized these methods.

Using a forced-choice procedure that was presented in the context of a game, Mennella et al. (2010a) determined children's sensitivity thresholds to 6-n-propylthiouracil (PROP). Based on the procedures of Anliker et al. (1991), children were presented, in succession, with samples of water and then three increasing concentrations of PROP (56, 180, and 560 μM) and asked to taste the sample without swallowing. If the solution tasted like "water" or "nothing," then they were asked to give the sample to Big Bird, a popular television character. If the sample tasted "bad," "yucky," or "bitter," children were asked to give it to Oscar the Grouch so he could throw it in his trash can. Children were classified into groups based on the concentration of the first sample, if any, that was given to Oscar the Grouch. This research has shown that children who are heterozygous at the *TASR38* gene locus are more sensitive to taste of PROP than were heterozygous adults, with the thresholds of heterozygous adolescents being intermediate (Mennella et al., 2010b), whereas homozygous children and adults did not differ in threshold. This task is one of the few that has been shown to be reliable (>85%; (Mennella et al., 2005) and valid, with 76% concordance between genotype and phenotype (Keller et al., 2010),

and is effective for children as young as 3 years of age (Mennella et al., 2010a).

In other studies, children were presented with a series of pairs of solutions, with one member of the pair being water and the other containing an aqueous tastant (i.e., paired comparisons). In some cases the aqueous tastants increased in concentration with each pair presented, and the child was required to indicate which sample of the pair contains the tastant, or tasted stronger. The lowest concentration that was detected successfully in one or two consecutive trials was recorded as the detection threshold (James et al., 1997). In other cases, the concentration of the tastant in each pair was determined by the child's ability to detect the tastant in the previous pair of samples. For example, in the staircase procedure, if the child incorrectly indicated which sample contained the tastant, in the next trial the next stronger tastant solution was presented; if the child was correct, a second presentation with the same concentration was given (Anliker et al., 1991).

A similar procedure, called the forced-choice tracking procedure, has been adapted to assess suprathreshold concentrations of tastants. In these studies, participants are instructed to taste, without swallowing, each solution and then to point to which of the pair they like better (or tastes stronger). For example, Mennella et al. (2011b) presented children with pairs of sucrose solutions that differed in concentration (3–36%). They were first presented with a pair of samples chosen from the middle range (6% vs. 24%) and were asked to taste each without swallowing and then to point to which of the pair they liked better. Like the staircase procedure described above, each subsequent pair was then determined by the subject's preceding preference choice. The procedure continued until the subject either had chosen a given concentration of sucrose when it was paired with both a higher and lower concentration or had chosen the highest (36% w/v) or lowest (3% w/v) sucrose solution two consecutive times. The entire task was then repeated with stimulus pairs presented in reverse order (e.g., weaker stimulus presented first in series 1; stronger stimulus first in series 2), thus preventing children from reaching criterion response based on bias toward first or second position. The geometric mean of the two sucrose concentrations chosen in series 1 and 2 estimated the participant's preferred level of sucrose.

By comparing the solution chosen in the first and second (reverse-order) task, one can achieve reliable results within each participant. As reviewed in Table 36.1, this procedure has been shown to be sensitive enough to examine individual differences (e.g., race, age, genetic) in sweet and salt taste preferences in children as young as 5 years of age and how differences in preferences relate to a variety of factors, including analgesia, obesity, dietary habits, and depression (Cowart and Beauchamp 1990; Mennella et al., 2010b, 2011b, 2005; Pepino and Mennella 2005a).

36.6.2.2 Scaling Techniques. Various types of scaling methods, that is, methods in which sensations to varying concentrations of suprathreshold stimuli are quantified, have been used to determine children's preferences and sensitivity to tastes. Depending on the child's age, these procedures involve presenting the child with a line or other type of scale that contains pictorial or verbal descriptors in a graded order. Although there has been no systematic determination of what scaling test is most appropriate for children at what age, some researchers have concluded that use of scales in children younger than 5 years can be problematic because they have not mastered the ability to rank things in order of magnitude (Guinard, 2001).

For children as young as 3 years of age, researchers typically use hedonic rating scales. Depending on the age of the child, these scales can consist of two to nine faces where one of the anchors is a happy face and the other a frowning face. While the increase in the number of faces potentially allows for finer-grain analyses of children's hedonic responses, preschool children do not appear to be able to reliably use scales that contain more than five faces (Chen and Resurreccion, 1996). However, little is known about the validity and reliability of these scales and at what age children begin using the entire scale rather than the anchors only.

Due to this gap in our knowledge about the use of hedonic face scales with children, researchers typically use them in combination with other measures. For example, when de Graaf and Zandstra (1999) tested the pleasantness of sucrose (0.03–0.88 M) in water and in orangeade in 9- to 10-year-old children, adolescents, and adults with a 5-point hedonic face scale, they found ratings of pleasantness correlated moderately with intake, and the strength of these correlations increased with age. The authors suggest that the increasing reliability observed with increasing age could be related to the development of cognitive capacity, which allowed older children to more consistently process and code the sensory information.

In addition to hedonic face scales, researchers have used other scales that include verbal descriptors (ranging from "no taste" to "very strong taste" (Anliker et al., 1991), and in some cases these verbal descriptors have been used with the Labeled Magnitude Scale (Coldwell et al., 2009). Here, children are shown a visual analog scale labeled with "barely detectable," "weak," "moderate," "strong," "very strong," and "strongest imaginable" and are asked to compare the intensity of each taste to oral sensations of any kind. Typically participants are trained on this scale by asking them to rate examples, including the sweetness of cotton candy, the bitterness of celery, or biting into a raw lemon or chili pepper. Although the use of verbal descriptors appears to be effective for measuring sensitivity in 9- to 10-year-old children (Coldwell et al., 2009; Graaf

and Zandstra, 1999), younger children may require a more concrete activity to visualize these descriptors. This has been done by asking children to place a ball into buckets that are placed at different heights to exemplify increasing taste intensities (Anliker et al., 1991; Turnbull and Matisoo-Smith, 2002). Despite gaps in knowledge about the reliability and validity of scaling techniques, there is some evidence that reliable results can be obtained from children if care is taken to use developmentally appropriate scales.

36.6.2.3 Rank Order. In rank-order methods, the goal is either to determine the child's most preferred concentration from a series of solutions, or to place all of the solutions in order of preference or stimulus intensity. In some cases children may be asked to taste all of the solutions in random order, after which they are asked to point to the one they like best (sweet preference inventory). This procedure has been used to determine whether children who chose higher concentrations of sucrose in tea have more dental caries (Jamel et al., 1997; Maciel et al., 2001a,b; Tomita et al., 1999). Their results suggest that socioeconomic status mediates the relationship between taste preference and number of dental caries in 4- to 6-year-old children (Tomita et al., 1999). However, one weakness of this methodology, which may limit the sensitivity of their results, is that children are required to remember and track a series of solutions in order to indicate their preferences, which may be difficult for preschool children.

Other approaches that are less cognitively demanding employ paired-comparison techniques in which all possible pairs of samples are presented and children are asked to choose which they prefer or which tastes stronger in each pair (e.g., Liem and Mennella, 2003). In a similar paradigm called rank by elimination, the sample that is selected from a pair in a trial is removed from the set, and children are asked to taste the remaining samples again and to point to the sample they like best or that tastes strongest. This procedure continues until a rank-order preference or intensity is established. Liem and Mennella (2003) used this procedure to determine sour preferences and sensitivity. A series of four citric acid (0.00–0.25 M) samples prepared in a gelatin base were tasted without swallowing by 5- to 9-year-old children and their mothers. They pointed to the sample that they liked best during trials of one session, and the sample that tasted most sour during trials of another session. This study demonstrated that children who showed preferences for higher sour concentrations were more likely to report that they had tried and liked sour candies compared to those who preferred lower concentrations of citric acid in gelatin. These findings are consistent with other research that has shown that preference for sour taste is correlated

with intake of fruits in infants (Blossfeld et al., 2007) and with previous consumption of protein hydrolysate formulas (Liem and Mennella, 2002) in 4- to 5-year-old children.

Other studies have used a bifurcated approach in which children are first asked to place the sample into either a "good/like" or a "bad/dislike" category. The degree to which they like the stimuli is determined using forced-choice methods, in which the children are presented with pairs of stimuli from each of the categories and asked to indicate which sample in the pair they prefer. This methodology has been used with children as young as 4 years of age to rank preferences to various foods with added sugar or salt (Sullivan and Birch, 1990), including sweetened beverages (De Graaf and Zandstra, 1999; Liem and de Graaf, 2004; Liem et al., 2004). It is important to note, however, that like the procedures previously discussed, little work has been done to validate ranking procedures with children.

36.6.2.4 Stimulus Presentation Methods.
When testing children, it is important to consider the method of presentation of the taste stimuli to the tongue. Studies in which evaluation of taste solutions were directly applied to small portions of the tongue versus the whole mouth have revealed inconsistencies in sucrose sensitivity in children relative to adults. Whereas children demonstrated high sucrose sensitivity relative to adults in local anterior regions (Temple et al., 2002b), this pattern of results was not observed when a whole-mouth procedure was used (James et al., 1997). These findings suggest that taste information may not be integrated as efficiently peripherally and/or centrally in children relative to adults. Moreover, research has shown that different regions of the tongue follow different patterns of growth throughout development: growth of the posterior region continues until approximately 15 years, whereas the fungiform-papilla-rich anterior region of the tongue attains adult size by the time children are 8–10 years of age (Temple et al., 2002a). Cessation of growth of the anterior region of the tongue by mid-childhood, however, does not mean that the anatomy and functionality of this region have reached adult levels of functioning. In a series of studies using videomicroscopy, Laing and colleagues have shown that in 8- to 9-year-old children, fungiform papillae and taste pores are smaller, papillae are rounder and more homogeneous in shape (Segovia et al., 2002), and the densities of fungiform papillae and taste buds are significantly higher compared to adults (Stein et al., 1994). As a result of the uneven pattern of growth of the tongue, care must be taken not to generalize evaluation of taste solutions directly applied to small portions of the tongue to other regions, which may be at a different stage of anatomical growth and function. This could lead to misperceptions regarding children's taste sensitivity.

36.7   IMPLICATIONS

36.7.1   Children's Different Sensory Worlds

Findings from experimental research during the past century, and especially in the past 20 years, have revealed that age is a particularly good predictor of individual differences in taste preferences. The convergence of findings from basic research reviewed herein reveals that children live in different sensory worlds than adults, preferring sweeter and saltier (and in some cases more sour) tastes than do adults and more intensely disliking bitter tastes. There is a striking paucity of research on umami taste in children; whether there are age-related changes, as observed for the other four basic tastes, remains unknown.

Further support for the concept that such hedonic responses are innate is suggested by research that has observed neonates within a couple hours of birth before their first feeding (Rosenstein and Oster 1988; Steiner, 1987). Such responses persist throughout childhood and influence dietary behaviors. For example, children generally dislike bitter-tasting foods such as leafy green vegetables, and as a result fewer than 15% of children between the ages of 4 and 8 years consume the recommended levels of vegetables (Guenther et al., 2006). Such responses are due in part to their genotype, which is related to their acceptance of a variety of foods (e.g., broccoli, brussels sprouts, cabbage) that contain bitter-tasting moieties such as glucosinolates. However, regardless of their genotype, just as children's responses to salt and sweet are influenced by early experiences, so are children's responses to bitter-tasting foods. Through repeated exposure to bitter-tasting foods, and to a variety of other foods from an early age, they can learn to like the taste of these once disliked foods. This has been demonstrated in infants who have been exposed to bitter-tasting protein hydrolysate formulas throughout infancy. Relative to those infants who had been fed milk-based formulas, these infants consumed more of and showed fewer orofacial responses of distaste to a bitter-tasting food (Mennella et al., 2009). This inherent plasticity of the chemical senses, which serves to mediate the effects of genetics through maturation and experience, ensures that we are not restricted to a narrow range of foodstuffs by virtue of a few preferences for or strong aversions to foods.

Although children are also born with an innate distaste for sour tastes, for some children this initial negative

Table 36.1 Summary of research findings on the five basic tastes during stages of development.

Development Stage/Methodology	Outcomes	References
SWEET		
Fetuses		
Consummatory responses		
Volume of amniotic fluid determined before and after injection of saccharin in amniotic sac.	↓ volume of amniotic fluid postinjection compared to pre-injection, suggesting ↑ intake of amniotic fluid after saccharin injections.	DeSnoo 1937; Liley 1972
***Preterm infants* (24–37 weeks gestational age at time of test; 1–29 days postnatal age)**		
Reflex-like responses		
Sucking responses measured for 1 min after drops of sweetened solution (33% glucose) or water were placed on tongue of newborns (30–36 weeks gestational age) over 5 trials.	↑ strength and frequency of sucking to sweetened solutions relative to water. ↑ strength and frequency of sucking to sweetened solutions as trials progressed. No such increase was observed with water.	Tatzer et al., 1985
Sucking responses measured when sweetened (30% sucrose + corn syrup) gelatin nipples and unsweetened nipples were placed in oral cavity of newborns (25–36 weeks gestational age).	↑ strength and frequency of sucking to sweetened relative to unsweetened nipple.	Maone et al., 1990
Spontaneous crying measured relative to baseline crying when 0.1 ml/min of aqueous 10% glucose, or water was placed in oral cavity of newborns (24–36 weeks gestational age) over 5 min.	↓ crying relative to baseline in newborns that received glucose but not those who received water.	Smith and Blass 1996
Variety of pain responses measured during and after painful procedures (e.g., heel lance, subcutaneous injection, or venipuncture) when a sweetened substance (glucose- or sucrose-sweetened water and/or pacifier), or unsweetened substance (water and/or pacifier), or no substance was present in oral cavity of newborns (24–37 weeks gestational age).	↓ pain response (e.g., crying, facial grimacing, limb movements) to sweetened relative to unsweetened or mildly sweetened pacifier or solution, or no solution.	Abad et al., 1996; Acharya et al., 2004; Bucher et al., 1995; Carbajal et al., 2002; Deshmukh and Udani 2002; Gibbins et al., 2002; Okan et al., 2007; Stevens et al., 2005

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Table 36.1 (*Continued*)

Development Stage/Methodology	Outcomes	References
Infants (**newborn to 2 years**)		
Reflex-like responses		
Sucking responses measured when a sweetened gelatin nipple, drops of aqueous sucrose (2–20%), an unsweetened nipple, or drops of water were placed in oral cavity of newborn infants (24–72 h old).	↑ sucking burst length to 15% aqueous sucrose relative to 5% sucrose or water. ↓ sucking latency to all sucrose concentrations relative to water. ↑ strength and frequency of sucking to sweetened relative to unsweetened nipples.	Crook 1978; Crook and Lipsitt 1976
Sucking responses measured when two quantities of response-contingent aqueous sucrose (5%) were delivered in consecutive 4-min periods to newborns (48–72 h old). One group of infants received the larger amount (0.03 ml/suck) whereas another received smaller amounts (0.01 ml/suck) during both periods.	↑ sucking bursts and inter-burst pausing for infants feeding larger versus smaller amounts.	Crook 1976
EEG was recorded from the frontal and parietal scalp regions in newborns (2-3 days old) who were presented with water followed by a sucrose solution.	↑ left-side activation relative to right-side activation in frontal and parietal regions to aqueous sucrose compared with water.	Fox and Davidson 1986
A variety of pain responses, movement, EEG, and heart rate measured during heel lance, circumcision, or subcutaneous injection when a sweetened substance (nutritive or nonnutritive), unsweetened substance, or no substance was present in oral cavity in newborns ranging from < 1 day to 30 days old.	↓ crying, facial grimacing, heart rate, recovery time, vagal tone, and limb movements to sweetened substance than to unsweetened substance, or no substance. Effects of nonnutritive sweeteners were similar to those of nutritive sweeteners. ↑ left frontal and parietal EEG activation to sweetened substance (indicating positive emotion) relative to water.	Abad et al., 1996; Bellieni et al., 2002; Blass and Hoffmeyer 1991; Blass and Watt 1999; Bucher et al., 2000; Carbajal et al., 1999; Fernandez et al., 2003; Fox and Davidson 1986; Gradin et al., 2002; Greenberg 2002; Ramenghi et al., 1996
Orofacial responses measured when a sweet solution or water was placed on the tongue in normal and anencephalic newborn infants who were 2–96 h old.	↑ sucking-like and mouthing responses, licking, facial relaxation, smiling, and hand-mouth contact to sweet solutions but not to water in normal and anencephalic infants. (Rosenstein and Oster (1988) report that fewer infants demonstrated raised cheeks (AU 6), narrowed or tightly closed eyes (AU 43 or AU 7 + 43), nose wrinkles (AU 9), or brows raised (AU 1 + 2) and/or lowered (AU 4) to sweet solutions than to nonsweet solutions.) ↑ amplitude of mouthing responses as concentration of sweet solution increased.	Barr et al., 1999; Ganchrow et al., 1983; Graillon et al., 1997; Nowlis and Kessen 1976; Peterson and Rainey 1910; Rosenstein and Oster 1988; Steiner 1973, 1977, 1979; Steiner et al., 2001

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Spontaneous crying measured relative to baseline crying when a sweet nutritive (i.e., 6%–24% sucrose, 10% glucose, 9% fructose, 17.5% lactose) or nonnutritive (e.g., 0.12% aspartame) solution or water was placed in oral cavity of infants who ranges from 1day to 12 weeks old.	↓ crying relative to baseline for some sweet nutritive (sucrose, glucose, and fructose) or nonnutritive solutions but not for water. No change in crying relative to baseline for lactose relative to water	Barr et al., 1999; Blass and Camp 2003; Blass and Smith 1992; Smith and Blass 1996; Zeifman et al., 1996
Heart rate measured when drops of aqueous sucrose (5% or 15%) or water were placed on the tongue of newborns (48–72 h old) in calm state.	↑ heart rate to 15% sucrose solution relative to 5% or water.	Crook 1976; Crook and Lipsitt 1976

Consummatory responses

Intake measured in newborns (1–3 days old) during brief-access (3 min) tests; bottles contained aqueous glucose, fructose, lactose, or sucrose (each ranging from 0.05 to 0.30 M) or water.	↑ intake of all sugar solutions relative to water. ↑ intake of sucrose and fructose than of lactose and glucose solutions. ↑ intake of 0.20 and 0.30 M solutions than of 0.05 and 0.10 M solutions	Desor, Maller et al., 1973
A longitudinal study measured intake in infants soon after birth (1–9 days old) and again at 6 months of age during brief-access (180 s) tests; bottles contained 0.2 or 0.6 M sucrose solution or water. Beauchamp and Moran (1984) tested a subset of these children again at 2 years of age using cups in brief-access (30 sec) tests. Cups contained 0.2 or 0.6 M sucrose or diluent (water or unsweetened Kool-Aid). Seven-day dietary records were also obtained from mothers at 6 months and 2 years.	↑ intake of sucrose relative to water in 6-month-olds and 2-year-olds who were regularly fed sugar water compared to those who were not regularly fed sugar water. Compared to intake at birth, ↓ intake of sucrose relative to water in 6-month-old infants who were not regularly fed sugar water. At 2 years of age, intake of sweetened Kool-Aid was higher than for unsweetened Kool-Aid regardless of whether they had been regularly fed sugar water.	Beauchamp and Moran 1982; Beauchamp and Moran 1984

Children (2–19 years)
Reflex-like responses

Pain response measured when children (5–12 years) immersed a forearm in a cold water bath while holding 24% sucrose or water in the oral cavity. Measures included threshold (latency to first report of pain) and tolerance (latency to remove arm).	↑ pain threshold to sucrose relative to water.	Mennella et al., 2010b; Miller et al., 1994; Pepino and Mennella 2005b
Facial EMG recorded in children (6–9 years) after placing drops of one of 8 concentrations of sucrose (0.05–1.34 M), 8 concentrations of quinine hydrochloride (0.08–2.31 M), NaCl (0.18 M), or citric acid (0.01 M) solutions or water on the posterior portion of the tongue.	↑ increased EMG activity in the zygomaticus and levator labii for sucrose relative to water. No difference in EMG responses in the zygomaticus to the four tastants, but for the levator labii, the difference in EMG activity was significantly lower for sucrose than for the other three tastants.	Armstrong et al., 2007

(*continued*)

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Table 36.1 (*Continued*)

Development Stage/Methodology	Outcomes	References
"Add to taste" preference procedure Adolescents (11–19 years) were presented two cups of tea, one sweetened with 30% sucrose and one unsweetened. After tasting the solutions in each cup, they were provided with a third cup and asked to pour one-half the unsweetened tea into this cup and then to add sweetened and unsweetened tea until the mixture was "tasty." At the end of the session the cups were weighed to determine the sugar concentration of the final mixture. Mothers were queried about health history during focal pregnancy and the child's history of infantile vomiting and diarrhea.	↓ concentrations of sweetened tea preferred by adolescents who experienced infantile vomiting and diarrhea, or whose mothers reported experiencing morning sickness during their pregnancy with them.	Lesham 1998
Five-point hedonic face rating scale Children (11–15 years) rated liking for six concentrations of aqueous sucrose (0.056–1.000 M) using a *five-point hedonic face rating scale*, ranging from smiling (extreme like), to neutral (just ok), to frowning (extreme dislike). Ratings for the two lowest concentration solutions were subtracted from those of the two highest concentration solutions. Positive difference scores were designated "high preference"; negative difference scores were designated "low preference."	↑ levels of biomarkers for bone growth in the high-sugar preference group compared to low-sugar preference group.	Coldwell et al., 2009
Sweet preference inventory Children (4–15 years) tasted five sweetened aqueous solutions in random order and pointed to the solution they liked best.	Children generally preferred the higher concentrations of sucrose. Children who preferred ↑ sucrose were from lower socioeconomic backgrounds, which in turn was associated with dental caries.	Jamel et al., 1997; Maciel et al., 2001a; Maciel et al., 2001b; Tomita et al., 1999
Ranking procedure A cross-sectional comparison of children (9–15 years, a subset of whom were twins) and adults who sipped without swallowing concentrations of sucrose (0.075–0.60 M) or lactose (0.30–0.40 M) and then ranked them from most to least preferred.	Most-preferred level of sweetness ↑ in male than in female children. Most-preferred level of sweetness ↑ in black than in white children. Most preferred level of sweetness ↑ in children than in adults. No significant differences ~~in sweet preference~~ between the monozygotic and dizygotic twin groups in level of sweetness most preferred.	Desor and Beauchamp 1987; Desor et al., 1975a; Greene et al., 1975

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A longitudinal study tested participants during adolescence (11–15 years) and adulthood, who sipped without swallowing four concentrations of aqueous sucrose (0.075–0.60 M) and then ranked them from most to least preferred.	↓ sucrose concentration rated highest as age increased; 50% of the children and adolescents, but only 25% of the adults, ranked the strongest sucrose concentration (0.60 M) highest.	Desor and Beauchamp 1987
Two-step, forced-choice ranking procedure Children (4–10 years), adolescents (14–16 years), and adults were presented five to seven concentrations of sucrose (0.03–0.88M) in water or orangeade (or six sweetened, salted, and plain foods in Sullivan and Birch (1990)). Stimuli were presented in random order, and participants were asked to categorize each using a hedonic face scale ranging from a smiling face for tastes they liked to a frowning face for tastes they did not like. After all stimuli were categorized, participants were asked to rank the beverages or foods from most preferred to least preferred within each category.	Most-preferred level of sweetness ↑ in children than in adolescents and ↑ in adolescents than in adults. Most-preferred level of sweetness ↑ in children who were repeatedly exposed to sweet foods at home. Children preferred sweetened ricotta cheese to salted or plain ricotta cheese. Preference for a sweetened novel food increased after it was repeatedly exposed at home.	De Graaf and Zandstra 1999; Liem et al., 2004; Sullivan and Birch 1990
Children (8–11 years) and adults were presented with sweetened (0.42 M added sucrose) orangeade with six concentrations of citric acid (0–0.065 M citric acid) or a sweetened (0.42 M added sucrose) yogurt with six concentrations of citric acid (0–0.17 M) in random order. Participants categorized each into categories using hedonic face scales ranging from smiling (most preferred), to neutral (just ok), to frowning (least preferred). Next, participants ranked their liking of the foods within each category. They then received repeated exposure to orangeade that contained 0.42 M sucrose and 0.02 M added citric acid over 8 days. The posttest was conducted in the same manner as the pretest.	↑ ranking for the sweetened orangeade with no added citric acid in both children and adults after the 8-day exposure period. preferences for the sweetened yoghurt with no added citric acid did not reach significance.	Liem and de Graaf, 2004
Paired-comparison, forced-choice ranking procedure Children (4–7 years) and adults indicated the level of sweetness they "liked best" in pairs of five or six concentrations (0–0.93M) sucrose-sweetened beverages (apple juice or orangeade). Parents completed questionnaires that asked about their children's consumption of sweet foods. In Liem et al., (2004) participants' responses in this test were compared to responses in the two-step, forced choice ranking procedure as described above.	Most-preferred level of sweetness ↑ in children than in adults. Most-preferred level of sweetness ↑ in those who were exposed to sweet foods at home. In Liem et al., (2004) 5-year-olds' and adults' responses were consistent between procedures (76% and 87%), whereas 4-year-olds showed 61.2% consistency.	Liem et al., 2004; Liem and Mennella 2002

(*continued*)

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Table 36.1   (*Continued*)

Development Stage/Methodology	Outcomes	References
Paired-comparison, forced-choice tracking procedure Children (5–12 years) and adults tasted pairs of aqueous sucrose solutions (3–36%) or pudding samples that varied in sweetness (13.4–36.2%) and chose the solution or pudding they liked better. Each subsequent pair contained the participant's preceding preferred concentration paired with an adjacent stimulus concentration, until the participant chose either the same sucrose concentration paired with a higher and lower concentration, or the highest or lowest concentration on two consecutive trials.	Most-preferred level of sweetness in water and in pudding ↑ in children and adolescents compared to adults. Most-preferred level of sweetness differed among children by genotypes at the TAS2R38 locus. Most-preferred level of sweetness ↑ in black children than in white children. Most preferred level of sweetness was associated with genetic variation within the TAS1R3 gene in adults but not children.	Mennella et al., 2005; 2010b; 2011b; 2012; Pepino and Mennella 2005b
Forced-choice sensitivity procedure Tested ability of children (8–9 years) and to detect sweet taste in binary mixtures of sucrose and salt solutions was measured. Samples were randomly ordered and consisted of sucrose concentrations (0–0.224 M) that were presented in water on eight trials and with 0.125M salt on eight trials.	Children identified both components (sweet and salty) in binary mixtures, except those containing the two lowest concentrations of sucrose. Fewer correct responses occurred with the mixtures than with sucrose alone. Similar results were found for adults.	Watson et al., 2001
Two-step, forced-choice discrimination procedure Children (4–5 years), were presented five concentrations of sucrose (0.22–0.29M) in orangeade in random order, and participants were asked to categorize each using a scale that visualized "most sugar" and "least sugar" by means of different numbers of sugar cubes. After all stimuli were categorized, participants were asked to order the stimuli within each category according to sweetness intensity.	While 5-year-old children were able to identify differences in sweetness across the five different sugar concentrations, 4-year-olds were not able to identify differences in sweetness across the five different sugar concentrations.	Liem et al., 2004
Paired-comparison, forced-choice sensitivity procedure Children (8–9 years) and adultsassessed a series of 12 concentrations of aqueous sucrose solutions (1.17 x 10⁻⁴ to 7.5 x 10⁻² M) paired with water, presented in ascending order, with left-right sample position randomized. Participants were instructed to indicate which of the solutions tasted stronger.	↑ sucrose detection threshold for boys than for girls. ↑ sucrose detection threshold for boys than for men and women.	James et al., 1997

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Labeled Magnitude Scale (LMS)

Children (11–15 years) rated the intensity of six concentrations of aqueous sucrose (0.056–1.000 M) along a visual analog scale labeled with "barely detectable", "weak", "moderate", "strong", "very strong", and "strongest imaginable". Subjects were asked to compare the intensity of each taste to oral sensations of any kind and were given examples including the sweetness of cotton candy, biting into a raw lemon, the bitterness of celery, and biting into a chili pepper.

Children who had previously indicated that they liked lower concentrations of sucrose more than the higher concentrations (classified as low preference) using the five-point hedonic face rating scale (described above) perceived the intensity of sucrose to be higher than children who were classified as high preference. This difference was significant for three of the six sucrose solutions tested (0.056 M, 0.1 M, and 0.32 M)

Coldwell et al., 2009

Time-intensity scale

Children (8–9 years) and adults rated the intensity and duration of sweetness over 90 s while holding sweetened water, orange drink, or sweetened custard in the oral cavity.

Children rated sweetness intensity higher and recorded shorter sweetness durations compared to adults.

Temple et al., 2002b

BITTER

Fetuses

Consummatory responses

Volume of amniotic fluid determined before and after injection of Lipiodol (iodized poppy seed oil, a radiocontrast agent).

↑ volume of amniotic fluid post- versus preinjection, suggesting ↓ intake of amniotic fluid after Lipiodol injections.

DeSnoo 1937; Liley 1972

Preterm infants **(24–37 weeks of gestational age)**

Sucking responses measured when drops of a quinine or water were placed on the tongue of newborns.

↓ sucking frequency in all but one infant.

Eckstein 1927

Infants **(newborn to 9 months)**

Reflex-like responses

Orofacial responses measured when drops of quinine or urea solutions, gentian tincture, or water were placed on the tongue of normal and anencephalic newborn infants who were 2–96 h old.

↑ Facial grimacing and gaping (AU 26 or AU 27) to bitter solutions relative to water in normal and anencephalic infants.
Transient ↑ in mouthing to quinine in crying infants.

Ganchrow et al., 1983; Graillon et al., 1997; Peterson and Rainey 1910; Rosenstein and Oster 1988; Steiner 1973, 1977, 1979; Steiner et al., 2001

Consummatory responses

Intake measured in newborn to 24-week-old infants during brief-access (30–180 s) tests; bottles contained aqueous solutions of urea (0.12–0.48 M) or diluent (e.g., water, or weak (0.07 M) sucrose solution).

No differential consumption of aqueous urea relative to water, or urea in sucrose relative to sucrose alone in newborns.
↓ intake of urea relative to diluent alone in 2- to 24-week-olds.

Desor et al., 1975b; Kajiura et al., 1992; Maller and Desor 1973; Schwartz et al., 2009

(continued)

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Table 36.1 (*Continued*)

Development Stage/Methodology	Outcomes	References
Intake and facial responses measured while infants (4–9 months old) were fed urea-flavored (0.24 M) and plain cereal by their mothers in a laboratory setting.	↑ intake of bitter-tasting cereals and ↓ facial expressions of distaste in infants routinely fed hydrolyzed casein formula than among those fed breast milk or milk-based formula.	Mennella et al., 2009
Children (3–19 years)		
Five-point hedonic face rating scale Children (4–5 years) were classified as either PROP tasters or nontasters according to whether they could taste a 0.56 mM PROP solution. They then rated liking for various food items ranging in perceived bitterness using a five-point hedonic face scale: smiling (extreme like), to neutral, to frowning (extreme dislike).	Children classified as PROP tasters gave ↓ ratings to raw broccoli and American cheese than did PROP nontasters.	Keller et al., 2002
Paired-comparison, forced-choice ranking procedure After a session in which children (7–10 years) were trained to understand differences in basic tastes, they were presented three bitter agents (urea (0.5 M), caffeine (0.08 M), tetralone (1.37 x 10⁻⁴ M)), one pair at a time, in all possible pairs of four solutions (bitter alone, sodium gluconate (0.03 M), bitter + sodium gluconate, water) and asked to indicate which of the pair tasted more bitter during one test session and which tasted better during another.	Addition of a sodium gluconate significantly ↓ the perceived bitterness and ↑ the acceptance of urea and caffeine. Addition of sodium gluconate significantly ↑ the perceived bitterness and ↓ acceptance of tetralone.	Mennella et al., 2003
Forced-choice sensitivity procedure Children (3–10 years), adolescents (11–19 years), and adults (mostly mothers) were asked to taste solutions of PROP (56, 180, and 560 µM). If the solution tasted like "water" or "nothing," children were asked to give it to Big Bird. If the drink tasted "bad," "yucky," or "bitter," children were asked to give the drink to Oscar the Grouch so he could throw it in his trash can. Participants were classified into four groups based on which was the first sample, if any, given to Oscar the Grouch. The A49P alleles of the *TAS2R38* gene were also genotyped. (In Keller et al. (2010), children were classified as tasters according to whether they gave 560 µM PROP to Big Bird or Oscar the Grouch.)	Children who were heterozygous *TAS2R38*/PROP tasters perceived ↓ PROP concentrations than did heterozygous adults, and heterozygous adolescents were intermediate. ↑ BMI in boys who were homozygous *TAS2R38* AA genotype/PROP nontaster relative to homozygous females. In 76% of children, *TAS2R38* genotype predicted PROP phenotype. Mennella et al. (2010a) conducted PROP testing a second time on a random sample of children all of whom were sensitive to PROP; reliability was 85.7%.)	Keller et al., 2010; Mennella et al., 2010a, 2005

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Staircase threshold procedure

Sensitivity of children (3–6 and 10–11 years old) to PROP was measured with 15 samples (0.0051–3.2 mM), offered to the child with a sample of distilled water. With the *staircase procedure*, if the child incorrectly indicated which sample contained PROP, the next stronger PROP solution was presented; if the child was correct, a second presentation with the same PROP concentration was given. If two correct choices were made at this concentration, testing continued at the next weaker PROP concentration. Four to five reversals were required to complete the test. PROP threshold was defined as the mean of the last four reversals. Children's liking of seven or eight foods was also assessed. (In Anliker et al. (1991), liking for foods in those classified as PROP tasters (i.e., those with thresholds < 0.05 mmol/L) was compared with nontasters, whereas in Turnbull and Matisoo-Smith (2002), ratings for foods were correlated with PROP thresholds.)

Children classified as PROP nontasters had ↓ thresholds for PROP than did adult nontasters. Children classified as tasters provided ↓ ratings for cheese. Children sensitive to the bitter taste of PROP were more likely to dislike the taste of raw spinach.

Anliker, Bartoshuk et al., 1991; Turnbull and Matisoo-Smith 2002

Sensitivity of children (3–6 years) to urea (3.75–3000 mM) was measured using the staircase procedure described above. The children were told a story about a goblin that makes drinks for baby goblins. A little goblin, who wanted to help make the drinks, put water in some of the bottles instead of "goblin drinks." Children were asked to help find the goblin drink in each of the pairs. A moderate concentration of urea was presented first. To shorten the procedure for younger children, concentrations were lowered by two steps until the first incorrect response, and then always increased or decreased one concentration step. The test stopped when two incorrect responses were given on the same concentration; detection threshold was defined as the first level above this concentration.

There were no age or gender differences in sensitivity to urea. The mean detection threshold for urea was 59.4 mmol/L.

Visser, Kroeze et al., 2000

(continued)

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Table 36.1 (*Continued*)

Development Stage/Methodology	Outcomes	References
Suprathreshold rating tests		
Children (5–7 years) who had already been identified as PROP tasters using the staircase procedure described above were presented 15 PROP samples (56–1800 μM) one at a time in random order and asked to rate the intensity of the solutions on a scale from 1 (no taste) to 5 (very strong taste).	Children identified as PROP tasters provided ↑ intensity ratings to the PROP solutions (i.e., perceived them to be stronger) than did PROP nontasters.	Aniliker et al., 1991
Children (3–6 years) tasted four PROP solutions (0.056 to 1.8 mM) and two samples of distilled water. After tasting each solution they were instructed to place a ball into one of three buckets that were placed at different heights to exemplify increasing taste intensities: mild, quite strong, and very strong. Intensity ratings for the strongest PROP solution (1.8 mM) and ratings for a variety of foods and beverages were analyzed.	Children more sensitive to PROP were more likely to dislike the taste of raw spinach.	Turnbull and Matisoo-Smith 2002
Labeled Magnitude Scaling		
Paper impregnated with PROP was placed on children's (10–11 years) tongues for 10 s, after which they rated its bitterness on a 10-cm scale: 0 = no sensation to 10 = most intense sensation they had ever experienced (e.g., the loudest sound they had ever heard). Those who scored > 4.2 were classified as PROP tasters.	PROP tasters were more likely to be described by their mothers as fussy eaters than were PROP nontasters.	Golding et al., 2009
SALT		
***Preterm infants* (24–37 weeks of gestational age)**		
Orofacial responses measured when drops of salty solutions or water were placed on the tongue.	Indifference in two-thirds of the infants and rejection in one-third.	Eckstein 1927
***Infants* (newborns to 24 months)**		
Reflex-like responses		
Orofacial responses measured when drops of salt solutions or water were placed the on tongue of newborn infants within hours of birth.	Indifference to salty solutions relative to water. Peterson & Rainey (1910) report that results were mixed; while some neonates grimaced, others exhibited contented sucking.	Peterson and Rainey, 1910; Rosenstein and Oster 1988; Steiner 1979

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Sucking responses measured when drops of NaCl (0.1–0.6 M) or water were placed in oral cavity of newborn infants (46–78 h old).	↓ burst length as the concentration of salt increased.	Crook, 1978
A cross-sectional comparison of newborns' and 4- to 8-month-olds' sucking responses during brief-access (30 s) multiple-bottle tests with aqueous salt solution (0.2 or 0.4 M) or water.	↓ number of sucks to 0.2 M salt solutions than to water in newborns. ↓ number of sucks to 0.4 M salt solution than to water in newborns and 4- to 8-month-olds.	Beauchamp, Cowart et al., 1994
A longitudinal study measured sucking responses monthly in 2- to 8-month-olds during brief-access (60 s) multiple-bottle tests of salted (0.15 M) or unsalted formula.	Indifference to salted versus unsalted formula in 2- to 3-month-olds. ↓ number of sucks to salted relative to unsalted formula in 6- to 7-month-olds (presumably from sweet suppression by salt). ↑ number of sucking bursts that were shorter in duration to salted relative to unsalted formulas in 4- to 7-month-olds.	Beauchamp, Cowart et al., 1994

Consummatory responses

Cross-sectional comparisons of intake of varying aqueous solutions of salt (0.10–0.40 M) or diluent (water or weak (0.07 M) sucrose solutions) in infants (newborn to 8 months) during multiple-bottle brief-access (30–180 s) tests. (Mothers in Crystal and Bernstein (1998) study were also asked to report experiences of nausea or vomiting during their focal pregnancy.)	No differential consumption of 0.1 M and 0.2 M salt solutions relative to diluent (water or weak sucrose solution) in infants < 4 months. Infants between 4 and 7 months consumed ↑ 0.1 M and 0.2 M salt solutions relative to water. Infants < 8 months of age consume less 0.4 M salt than water. Infants of women who reported moderate or severe vomiting during early pregnancy showed ↑ preferences for moderate concentrations of salt solutions over water compared to infants of women who reported no symptoms.	Beauchamp et al., 1986, 1994; Crystal and Bernstein 1998; Desor et al., 1975b
Longitudinal studies measured intake of salted solutions (0.17 M and 0.34 M) or water in 2- and 6-month-olds during multiple-bottle brief-access (60–120 s) tests. Mothers reported their infants' birth weight and whether they had been exposed to starchy table foods.	Negative correlation between birth weight and acceptance of 0.017 M and 0.34 M salt solutions relative to water at 2 months but not at 6 months. ↑ intake of 0.17 M and 0.34 M salt solutions relative to water in 6-month-olds whose mothers reported that they fed their infants starchy table food.	Stein, Cowart et al., 2006, 2012
Intake measured when infants (16–25 weeks) were fed salted or plain cereal by their mothers on four separate days.	↑ intake of salted relative to plain cereal at 16 weeks. ↑ consumption of salted than unsalted cereal in younger infants than in older children.	Harris et al., 1990

Table 36.1 (*Continued*)

Development Stage/Methodology	Outcomes	References
Intake and facial responses measured while infants (4- to 9-months) were fed salted (0.1 M) or unsalted cereal by their mothers in a laboratory setting. Mothers reported whether their children had been exposed to table foods, and if so, which foods.	↑ intake of salted relative to unsalted cereals in infants who were eating cheese at home versus those who were not.	Mennella et al., 2009
***Children* (7 months to 19 years)** **Consummatory responses**		
A cross-sectional study measured intake in children (7–72 months) during brief (30 s) access to multiple cups containing 0.17 or 0.34 M salt solutions or diluent (i.e., water or soup).	↑ intake of 0.17 M salt solution relative to water, but intake of 0.34 M did not differ from that of water in 7- to 24-month-olds. ↓ intake of 0.17 M and 0.34 M salt solutions relative to water in 31- to 72-month-olds. ↑ intake of 0.34 M salted soup relative to 0.17 M salted and the unsalted soup in 36- to 72-month-olds.	Beauchamp et al., 1986; Cowart and Beauchamp 1986
"Add to taste" preference procedure Adolescents (11–19 years) were presented two cups of tomato soup, one salted (3.3% w/w) and one unsalted. After tasting the soups in each cup, they were provided with a third cup and asked to pour one-half the unsalted soup into this cup and then to add salted and unsalted soup until the mixture was "tasty." At the end of the session the cups were weighed to determine the salt concentration of the final mixture. Mothers were queried about health history during the focal pregnancy and the child's history of infantile vomiting and diarrhea.	↑ concentrations of salted soup preferred by adolescents who had experienced infantile vomiting and diarrhea or whose mothers reported experiencing morning sickness during their pregnancy with them. Adolescents preferred ↑ concentration of salt in soup if they reported adding more salt to food.	Lesham 1998
Ranking procedure Children (9–15 years, a subset of whom were twins) and adults tasted four or five concentrations of salt in water (0.05–0.4 M) or in soup (0.025–0.10 M) and either indicated which was their favorite or ranked them from most to least preferred.	Most-preferred salt concentration ↑ for children than for adults. Most-preferred salt concentration ↑ in black than in white children. No significant differences in preference for salt solutions between monozygotic and dizygotic twin groups. Most-preferred level of salt in soup in Korean adolescents was ↑ if they frequently ate at fast food restaurants.	Desor and Beauchamp 1987; Desor et al., 1975a; Greene et al., 1975; Kim and Lee 2009

Two-step forced-choice ranking procedure
Children (4–5 years) were presented salted, sweetened, and plain tofu and ricotta cheese in random order and asked to categorize each into hedonic categories (e.g., like, dislike) using face scales and then to rank the foods from most preferred to least preferred within each category. Children were then exposed to salted, sweetened, or plain tofu 15 times over 9 weeks. The ranking procedure was conducted two additional times throughout the exposure phase and at the end of 9 weeks.

Children initially ranked salted ricotta cheese ↑ than plain ricotta.
Children exposed to salted tofu showed ↑ preference for salted tofu and ↓ preference for plain tofu.
Children exposed to plain tofu showed ↑ preference for plain tofu and ↓ preference for salted tofu.

Sullivan and Birch 1990

Paired-comparison, forced-choice ranking procedure
Children (3–7.5 years) ranked the level of saltiness they preferred in all possible pairs of samples chosen from three or four concentrations (0–0.56 M) of salt solutions or soup.

Most children preferred plain water more than salt water solutions.
Most children preferred salted to unsalted soup.
Most-preferred concentration of salt in soup was ↑ than typically observed with adults.

Beauchamp and Cowart 1990; Cowart and Beauchamp 1986

Paired-comparison, forced-choice tracking procedure
Children (3–11 years) and adults tasted pairs of salted soups (0.01 M–1.00 M) and chose the sample they liked better. Each subsequent pair contained the participant's preceding preferred concentration paired with an adjacent stimulus concentration, until the participant chose either the same concentration of salt paired with a higher and lower concentration, or the highest or lowest concentration on two consecutive trials. The task was then repeated with the members of the stimulus pairs presented in reverse order. The geometric mean of the salt concentrations chosen in the two trial series provided the estimate of the child's most preferred level of salt.

Children preferred ↑ concentrations of aqueous salt than did adults.
No racial differences between children were evident, nor did degree of salt exposure affect preferences.

Beauchamp and Cowart 1990

Forced-choice sensitivity procedure
Children (8–9 years) and adults were presented 16 test trials in random order presenting sucrose solutions (0.056–0.224 M), and binary mixtures of NaCl (0.032–0.125 M) mixed with each of the concentrations of sucrose, or water, to determine if they could detect salt taste in aqueous binary mixtures of sucrose and salt.

Children identified both components (sweet and salty) in all binary mixtures except the two lowest concentrations of sucrose.
Fewer correct responses occurred with the mixtures than with the single tastant.
Similar results were found for adults.

Watson et al., 2001

(continued)

Table 36.1 (*Continued*)

Development Stage/Methodology	Outcomes	References
Paired-comparison, forced-choice sensitivity procedure		
Adolescents (12–13 years) were presented a three-alternative, paired-comparison, forced-choice sensitivity procedure in which each of seven aqueous salt solutions (0.86–25.6 mM) was presented in ascending order with two additional cups containing water. The participants were informed that only one cup of each triad contained a very dilute salt solution, and that the others contained just water. The lowest salt concentration that was detected successfully in one or two consecutive trials was recorded as the detection threshold.	↑ salt detection threshold in adolescents who reported liking soup.	Kim and Lee 2009
After identifying a threshold for salt using the paired-comparison, forced-choice sensitivity procedure described above, children (5–16 years) with cystic fibrosis and matched controls were presented four cups that contained the threshold concentration and four cups containing water. If the subject succeeded in accurately distinguishing the threshold solutions from the water, the procedure was repeated with the next lower salt concentration. This was continued until the participant was no longer able to distinguish the salt concentration from water, at which point the next higher concentration was deemed to be the salt concentration threshold.	Threshold concentrations of salt did not differ between children with cystic fibrosis of the pancreas and age-matched controls.	Wotman et al., 1964
Suprathreshold rating test		
Children (7–12 years) and adults rated the saltiness and preference for five bags of popcorn that differed in saltiness (0–3 M) using a seven-point Likert scale: 1 = least salty/preference, 7 = most salty/preference.	Children liked popcorn with ↑ concentrations of salt than did adults.	Verma et al., 2007

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SOUR

***Preterm infants* (24–37 weeks of gestational age)**		
Sucking responses measured when drops of pure lemon juice or water were placed on the tongue of newborn infants.	↑ reflex salivation accompanied by apparent increases in sucking vigor and sometimes retching.	Eckstein 1927
***Infants* (newborns to 24 months)** **Reflex-like responses**		
Orofacial responses measured when drops of citric acid or water were placed on the tongue of normal and anencephalic newborn infants within hours after birth.	↑ facial squinting (AU 6 + 7) and pursing (AU 18) responses to sour solutions relative to water.	Ganchrow et al., 1983; Peterson and Rainey 1910; Rosenstein and Oster 1988; Steiner 1973; Steiner 1977, 1979; Steiner et al., 2001
Consummatory responses		
Intake in infants (newborn and 15–20 months) was measured during brief-access tests with bottles or cups contained aqueous solutions of citric acid (0.013–0.065 M) or diluents (water, weak 0.07 M sucrose). The older infants were grouped according to their intake of these solutions. Those who consumed more of the 0.029 M or the 0.065 M solutions relative to either water or the 0.013 M solution were grouped in the high-sour group. Infants' food intake was assessed with 3-d food diaries.	No differential consumption of aqueous citric acid relative to water, but addition of citric acid to a sucrose diluent ↓ consumption relative to aqueous sucrose alone. ↑ fruit intake in infants with high sour preferences relative to those with low sour preferences.	Blossfeld et al., 2007; Desor et al., 1975b
Intake and facial responses in infants (4–9 months) measured while their mother fed plain cereal during one session and sour-flavored cereal (0.006 M citric acid added) during another. Infants' milk feeding history was recorded.	↑ intake of sour-tasting cereals in infants fed hydrolyzed casein formula compared to those fed breast milk or milk-based formula.	Mennella et al., 2009

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Table 36.1 (*Continued*)

Development Stage/Methodology	Outcomes	References
Children (3–12 years)		
Rank-by-elimination procedure		
Children (5–9 years) and their mothers were presented four concentrations of citric acid (0.00–0.25 M) in a gelatin base. They tasted without swallowing each gelatin and pointed to the one that they liked best during one session or the one that tasted most sour during another; that gelatin was then removed, and children were asked to taste the remaining three gelatins again and indicate which of the three was most preferred or tasted most sour. This procedure continued until a rank-order preference and sour intensity were established.	More than one-third of the children, but virtually none of the adults, ranked the highest concentration of citric acid in gelatin as one of their most preferred. Those children who preferred the highest concentration of citric acid in gelatin were more likely to report that they had tried and liked sour candies compared to those who preferred lower concentrations of citric acid in gelatin.	Liem and Mennella 2003
Paired-comparison, forced-choice ranking procedure		
Children (4–7 years) were presented six concentrations of citric acid (0–0.07 M) in apple juice and ranked the concentration of citric acid most preferred in all possible pairs of solutions. Mothers were queried about the type of formula children had been fed as infants.	Children 4–5 years old who were fed protein hydrolysate formulas preferred ↑ concentrations of citric acid in juice than did 6- to 7-year-old children fed similar formulas.	Liem and Mennella 2002
Two-step forced-choice ranking procedure		
Children (8–11 years) and adults were presented with six concentrations of citric acid dissolved in either orangeade (0–0.065 M citric acid) or a yogurt base (0–0.17 M) in random order and asked to categorize each into hedonic categories using hedonic face scales ranging from smiling (most preferred), to neutral (just ok), to frowning (least preferred). Next, participants ranked their liking of the foods within each category. They then received repeated exposure to orangeade that contained 0.42 M sucrose and 0.02 M added citric acid over 8 days, and posttests were conducted in the same manner as the pretest.	Children's most-preferred orangeade during pretest was similar to that observed during the posttest. Similar results were obtained for yogurt.	Liem and de Graaf 2004

UMAMI

Infants (newborns to 24 months)

Reflex-like responses

Orofacial responses measured when drops of MSG solutions or diluent (i.e., water or soup) were placed on the tongue of normal newborn infants within hours of birth.	↑ sucking-like and mouthing responses, licking, facial relaxation, smiling, hand-mouth contact to soup with MSG relative to soup alone. MSG in water did not elicit positive facial expressions relative to water alone.	Steiner 1987

Consummatory responses

Measured intake of MSG solutions (0.05–0.40%) or diluent (i.e., soup, water) in 2- to 24-month-old, well-nourished and/or malnourished infants during multiple-bottle brief-access (60 s) tests.	Malnourished and well-nourished infants consumed ↑ soup containing MSG relative to soup containing no MSG. Well-nourished infants consumed ↓ aqueous MSG relative to water.	Beauchamp and Pearson 1991; Vazquez et al., 1982
Intake and facial responses were measured while infants (4–9 months) were fed glutamate-flavored (0.02 M) and plain cereal or broth by their mothers in an infant-led feeding paradigm. Infants had been routinely fed hydrolyzed casein formula or cow's milk for varying amounts of time.	↑ intake of savory-tasting cereals in infants routinely fed hydrolyzed casein formula than in those fed milk-based formula or breast milk. ↑ smiling during feeding savory-tasting cereals in breastfed infants and those routinely fed hydrolyzed casein formula than in those fed milk-based formula. ↑ acceptance of savory-tasting broth relative to plain broth in infants fed hydrolyzed casein formula for 3 or 8 months but not for 1 month.	Mennella et al., 2009; Mennella and Castor, 2012

Abbreviations: AU, action units (from (Ekman and Friesen 1978) Facial Action Coding System); EEG, electroencephalogram; EMG, electromyography; PROP, 6-n-propylthiouracil; $TAS2R38$, taste receptor, type 2, member 38 (a bitter-receptor gene); $TAS1R3$, taste receptor, type 1, member 3 (a sweet-receptor gene); MSG, monosodium glutamate; M, molarity or moles per liter of solute.

response to sour transforms into preference by 18 months of age (Blossfeld et al., 2007). By the time children have reached middle childhood, approximately one-third display a strong preference concentrated sour tastes (e.g., 0.25 M citric acid; (Liem and Mennella 2003). These sour preferences have been shown to be related to intake of sour-tasting foods such as fruit throughout infancy (Blossfeld et al., 2007) and childhood (Liem and Mennella 2003), as well as personality characteristics, such as sensation seeking (Urbick 2000).

36.7.2   Preferences Counter-adaptive to Our Modern World

Why is it that children reject the very tastes that are associated with so many healthful foods, and prefer those that are associated with high-calorie, fatty foods? From an evolutionary perspective, it has been argued that children's responses to tastes enhance survival by attracting them to foods that contain energy, minerals, and vitamins (e.g., mother's milk, fruits) during periods of maximal growth and inhibiting ingestion of potentially toxic substances, many of which are bitter. Children's innate taste preferences, which reflect their biological needs, help to explain why they like to eat the foods and beverages they do. For example, Coldwell et al., (2009) have shown that preferences for sweet-tasting foods are correlated with periods of high growth. In our modern society, this once adaptive link between sweet preference and biological need may leave children especially vulnerable to negative long-term consequences, including obesity and dental caries.

Although children's hedonic responses to the basic tastes may have once enhanced their survival, today children's predisposition to prefer sugar and salt and to avoid bitter-tasting foods, such as green vegetables, is no longer adaptive in an obesogenic environment that contains an overabundance of processed carbohydrate-rich and salty foods. Approximately a third of children more than 2 years of age are overweight (Ogden et al., 2010); this excess weight is associated with a number of serious health complications that were previously considered rare in children, such as type 2 diabetes and high blood pressure (Lee et al., 2006; Maynard et al., 2003). Given that unhealthful dietary patterns established in childhood track into adulthood (Mikkila et al., 2004), it is necessary to develop a thorough understanding of the basic biology of taste and the mechanisms involved in the development of taste and flavor preferences throughout childhood.

The innate rejection of bitter-tasting substances in children, in addition to reducing consumption of green vegetables, also plays a central role in children's hesitance to take oral medications (for review, see Mennella and Beauchamp 2008). Although many solid oral dosage forms

(e.g., pills, tablets) have the advantage of masking or encapsulating the bitter tastes of active compounds, such methods are ineffective for many children because they often cannot or will not swallow pills or tablets. Most children, at some point in their lives, are required to take medicine, which often tastes bitter, and some will refuse to take it. When children refuse to take a single dose–let alone a full course of medication–because it tastes bad to them, that bitter taste thwarts the benefits of even the most powerful drug. Thus, the main challenge of administering medicine to children is a matter of taste because drugs, by their very nature, often taste unpleasant and bitter. The unpleasant taste of a medicine is a sensory expression of its pharmacological activity–the more potent the drug, the more bitter-tasting and/or irritating it will be. And the more bitter-tasting and irritating its flavor, the more likely the drug will be rejected by children.

A recent study explored the relationship between genotype of only one of the 25 bitter receptor genes (*TAS2R38)* and medication history (Lipchock et al., 2012) and found that children younger than 10 years with at least one bitter-sensitive allele (PP or AP genotype) were more likely to have taken medicine in solid formulation than were bitter-insensitive (AA genotype) children. It was hypothesized that the resistance to taking bitter liquid formulations may be related to compliance and that bitter-sensitive children may be resistant to taking bitter liquid formulations and are more motivated to try medicine in pill form as an alternative. These findings open up another important area for taste psychophysics and genetics, suggesting that taste genetics and individual differences in bitter sensitivity could be an important factor in formulation choice and compliance in the pediatric population.

36.8   CONCLUSIONS

Although this area of research has enjoyed more than a century of basic research, we have many gaps in knowledge in an area that has important implications for the health of our children. Although many developmentally appropriate methodologies and approaches have been created to test taste sensitivity and preference throughout childhood, more work needs to be done to validate and standardize these procedures across taste modalities. In some cases, the question may need to be asked several ways and the convergence of findings from different methodologies is required to give confidence to the conclusions.

While each measure has its limitations, the convergence of research findings supports the conclusion that the ability to detect sweets is evident very early in human development and that its hedonic tone changes throughout childhood. With respect to bitter, newborns respond with

highly negative facial expressions to concentrated quinine and urea, but they do not reject moderate concentrations of urea. The reason for this difference remains unclear. Newborns also reject the sour taste of strong citric acid solutions; however, at least for some children, this initial rejection transforms into a preference before two years of age. Because only a handful of studies on sour tastes have been conducted, it is not known whether there are developmental changes in sensitivity or preference for sour-tasting foods and beverages. Conclusions regarding the response to savory and salty tastes are more problematic, and further research is needed. With regard to salt taste, studies measuring intake and facial expressions suggest that the newborn infant is indifferent to and may not detect salt. However, tests in which salt has been presented within an appropriate context (i.e., soup), children younger than two years of age have shown preferences for this taste.

The bottom line is that unhealthful behaviors, such as the overconsumption of sweet and salty foods and the rejection of bitter green vegetables or unpalatable medications, are a reflection of the child's basic biology. From an evolutionary perspective, the senses that evaluate what is put into the mouth have likely evolved to reject that which is harmful and seek out that which is beneficial. In particular, rejection of bitter-tasting and irritating substances is thought to have evolved to protect the animal from being poisoned and the plant producing these chemicals from being eaten.

That being said, our biology is not our destiny; children learn through repeated experiences with various types of foods. A case in point is sweet taste. Research has shown that children learn in which contexts sugar is typically found through experience (Beauchamp and Cowart 1985; Beauchamp and Moran 1982). That is, the sensation of sweetness may be context dependent and can acquire meaning through learning. In a recent studies, children who were exposed to a sweetened orange-flavored beverage (Liem and de Graaf 2004) or a sweetened food (Sullivan and Birch 1990) over the course of eight to fifteen days exhibited a stronger preference for the sweetened beverage or food at the end of the exposure period, but not a significant preference for the sweet taste in another context (e.g. yogurt or ricotta cheese), suggesting that this learning may be context-dependent(Liem and de Graaf 2004). That is, through familiarization, children develop a sense of what should, and what should not, taste sweet (Beauchamp and Cowart 1985; Pepino and Mennella 2005a).

Such learning is not confined to sweet taste, as evidenced by studies of salt taste perception (Beauchamp, Cowart et al., 1986; Cowart and Beauchamp 1986), as well as by studies examining more complex food media such as extensively hydrolyzed protein infant formulas (ePHF) formulas which taste bitter, sour, and savory and have unpleasant aromas (Mennella and Beauchamp 2005). In a series of randomized clinical trials, we have shown that there is a sensitive period before 4 months of age during which experience can shift the hedonic tone to the flavor of the formula (Mennella et al., 2004; Mennella et al., 2011a). Evidence that such flavor programming lasts beyond childhood is suggested by the finding that children who were fed ePHF as infants are programmed to like the taste of not only ePHF when they are older, but also the taste of foods that are more savory (e.g., chicken), sour (e.g., lemon), and bitter (e.g., broccoli) (Liem and Mennella 2002; Mennella 1998; Mennella and Beauchamp 2002; Mennella et al., 2009; Mennella et al., 2006).

In conclusion, it is a public health priority to develop standardized psychophysical methods that are appropriate for children of all ages. More insight into the "taste world" of children will initiate new perspectives that will aid in the development of evidence-based strategies for improving children's food preferences and eating behaviors and help ameliorate bitter taste, which is the primary culprit for children's refusal to accept liquid formulations.

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