

# Chemosensory Development in the Fetus and Newborn

Joy V. Browne, PhD, CNS-BC

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The chemosensory system is one of the earliest emerging systems in fetal development. Smell is detected through the epithelium of the nasopharynx and taste through the tongue. Anatomical structures and innervation are already present in the first and early second trimesters. Early fetal experience with the mother's specific diet through the amniotic fluid provide for a continuous sensory environment from fetal to newborn life. Both term and preterm infants detect and discriminate odor and taste and prefer their own mother's familiar odor and taste. Exposure to the newborn mother's amniotic fluid and breast milk provide physiologic and behavioral changes that influence early attachment relationships and feeding outcomes. Strong, ill-timed, and unfamiliar odors can interfere with infant physiologic stability and behavioral organization. Hospital chemosensory environments should be adapted to the specific expectations and needs of the infant and mother particularly during delivery and the neonatal intensive care unit experience.

**Keywords:** Smell; Taste; Chemosensory development; Fetal development; Infant; Newborn

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Gustatory and olfactory sensory influences on human development are less obvious than those of the other senses. However, they not only have a profound effect on how environmental information is detected and processed but also make significant contributions to cognitive and emotional interpretation of daily experiences, adding to the richness of human experience. The processing of the taste and smell sensory environment significantly influences the entire developmental life of individuals from day one. At a very basic level, the sense of smell and taste provide protection by causing, for example, avoidance of noxious and potentially caustic food or other dangerous compounds. On the other hand, they provide enjoyment and satiation of a fine gourmet dinner or hedonic appreciation of sweet-smelling flowers. Although often not consciously detected, smell and taste significantly influence relationships between parent and child, providing identification, protection, and nurturing of offspring. Relationships between individuals, and even those of romantic attraction are

now related to signals emanating from contact with odorants and pheromones.

Neurophysiologically, olfactory and gustatory connections are closely related to centers of cognition and emotion in the brain and provide for associations beyond just sensations of taste and smell. For example, a familiar smell or taste of holiday food may bring feelings and memories of pleasant experiences. Alternatively, odor and taste can also bring less pleasant memories and emotions such as experiences at a dentist's office or of a food that previously caused illness. Because of the early development of the smell and taste systems, early associations can influence thoughts, emotions, and behaviors throughout the lifespan.

Mammalian fetal sensory development comes in an invariant series, with the tactile/kinesthetic and chemosensory systems the earliest functioning and responsive to stimulation, implicating the importance of these foundational sensory systems for later development. Current research reveals consistency of responses as the fetus transitions from fetal to newborn periods in preparation for locating food, eating, and attachment to the specific mother to whom the baby is born.<sup>1,2</sup> These findings have implications for the premature as well as the term newborn. Newborns not only detect, discriminate, and have preferences for odors and tastes based on earlier fetal exposure but also show association learning of both pleasant and unpleasant taste and odor experiences that influence their behavior throughout their lifetime.<sup>2</sup> Clinically, an understanding of chemosensory system development and function provide a foundation for interventions to support early physiologic stability, oral feeding, and attachment relationships.

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*From the University of Colorado Denver School of Medicine and the Children's Hospital, Department of Pediatrics, JFK Partners, Aurora, CO. Address correspondence to Joy V. Browne, PhD, CNS-BC, University of Colorado Denver School of Medicine and the Children's Hospital, Mailstop C234, 13121 E. 17th Ave., Room L28-5117, P.O. Box 6511, Aurora, CO 80045. E-mail: [browne.joy@tchden.org](mailto:browne.joy@tchden.org).*

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## Fetal Development of Gustatory and Olfactory Systems

The chemosensory systems develop anatomically and functionally in the first trimester and early second trimester. Taste cells are clustered in taste buds, which are located on the tongue, palate, pharynx, epiglottis, and upper third of the esophagus.<sup>3</sup> On the tongue, taste buds are located in the papillae, which are embedded in the epithelium and determine the primary tastes of sweet, sour, salty, and bitter as shown in Fig 1. The anterior tongue is innervated by the chorda tympani branch of the facial nerve, and the posterior is innervated by the glossopharyngeal nerve. Taste information is transmitted from the taste buds to the cerebral cortex via synapses in the brain stem and thalamus as demonstrated in Fig 2. Volatile odor molecules are released from food or drinks and pumped into the back of the nasal cavity where they can be detected by smell as well as taste. The somatosensory system is also involved in localization and causes the volatile odorant to be perceived as flavors in the mouth.<sup>3</sup>

At birth, infants have a full anatomical and functional repertoire of taste buds and are able to detect and discriminate tastes. Both tongue size and taste buds increase during childhood and adolescence.<sup>4</sup> Taste buds, innervation, and papillae development begin at approximately week 6 to 7 and continue through approximately week 18 of gestation. Taste buds are possibly functional with taste detection by 14th week of gestation.<sup>5,6</sup>

The olfactory system includes the main olfactory epithelium in the nasopharynx, the main olfactory bulb, the trigeminal system, and the vomeronasal system. Structural differentiation occurs in the first 3 months of gestation. By the seventh to

eighth week there are ciliated olfactory neuroreceptors to innervate the forebrain before the olfactory bulb is differentiated and form a visible olfactory nerve. After the olfactory bulb forms at 6 to 8 weeks, the dendrites to the glomeruli are observed. The trigeminal system originates from the cranial nerve and responds to tactile stimulation by about 8 to 10 weeks and should support common chemical sensations. Nasal tissue supporting and enclosing the human chemoreceptors takes the form of a “miniature nose” at about 6 to 8 weeks of gestation and is reliably detected by about 11 to 15 weeks on ultrasound.<sup>7</sup> Until the sixth month or earlier, the nasal orifices are plugged but then dissolve and allow fetuses to inhale amniotic fluid.<sup>8</sup> Respiratory efforts, swallowing, and activity influence the flow of fluid bathing the nasal pathways and provide contact between the nasal epithelium and the ever changing amniotic fluid content.

The olfactory sensory neurons in the epithelium of the nasopharynx are stimulated by either amniotic fluid or air-based odorants and transmit signals to the olfactory bulb of the brain as demonstrated in Fig 3. From there, information is relayed to the olfactory cortex.<sup>9</sup> The pathways through the thalamus to the orbitofrontal cortex are thought to be responsible for the perception and discrimination of odors. In addition, olfactory information is transmitted from the amygdala to the hypothalamus and to the hippocampus, which are thought to mediate the emotional and motivational aspects of smell and many of the physiologic and behavioral effects of odors.<sup>3</sup>

The placenta is increasingly permeable to blood solutes, reinforcing potential influence of the maternal dietary aromas in the amniotic fluid. Both amniotic fluid and milk originate in the mother's blood system, resulting in a chemically similar “aromatic signature” for the fetus and then the newborn,

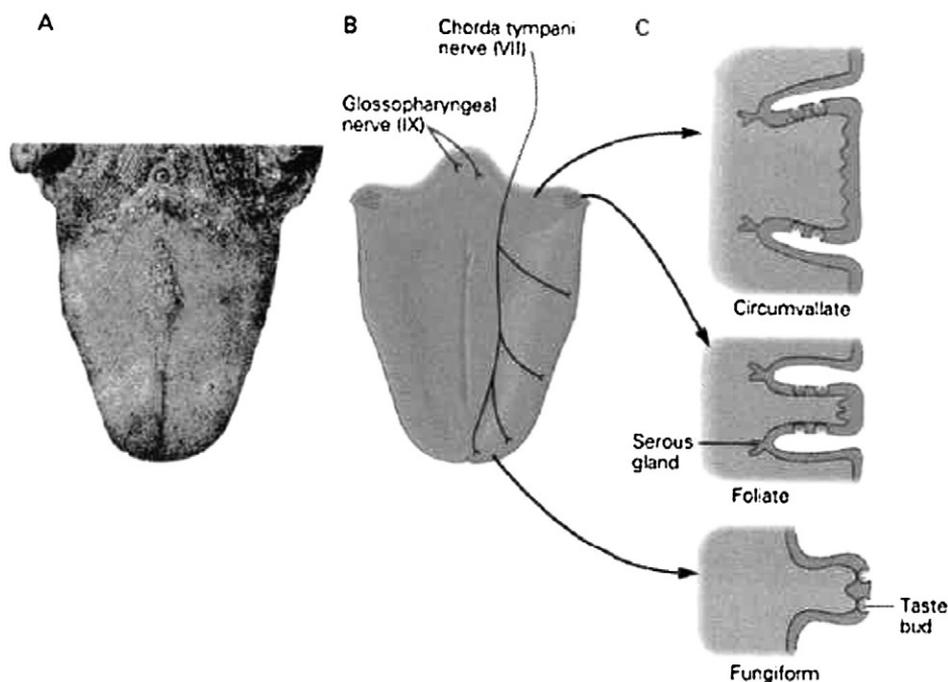
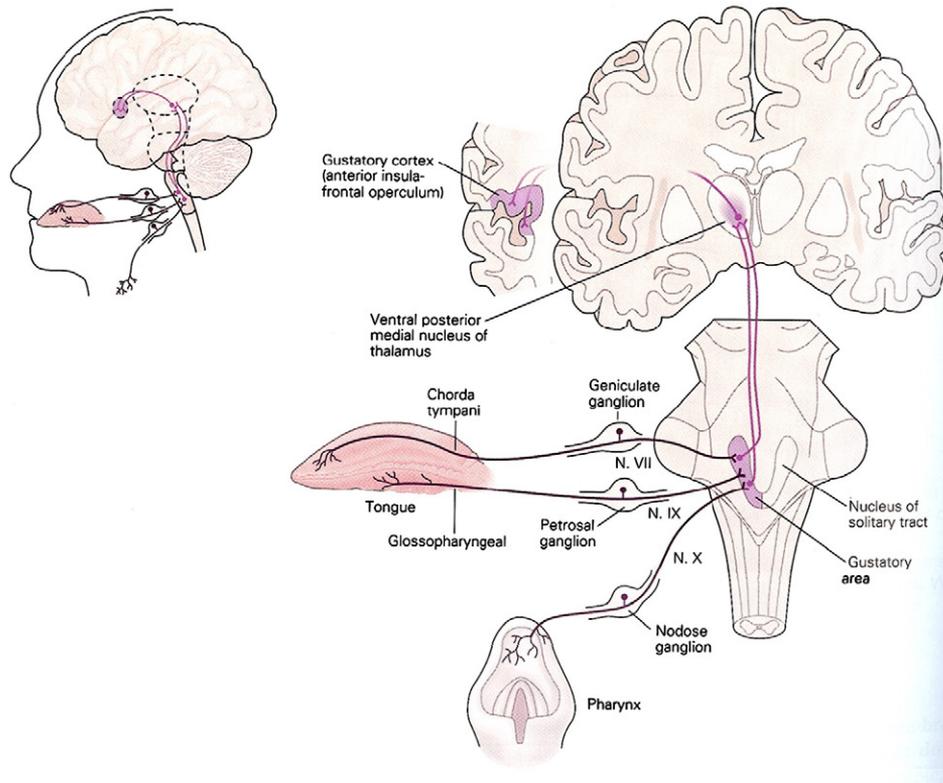


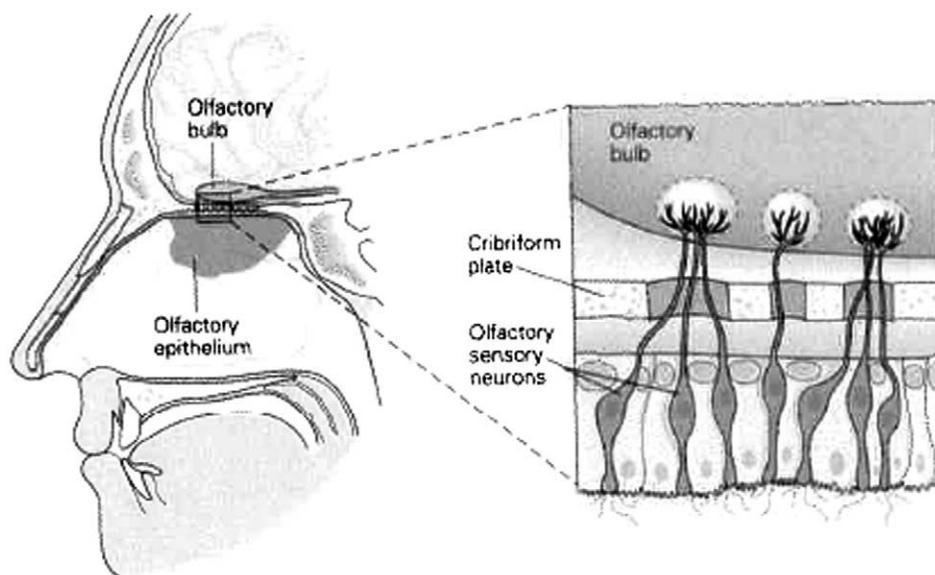
Fig 1. Tongue innervation.



**Fig 2.** Chemosensory development.

which is regulated by her unique diet.<sup>1,10-12</sup> Fetuses detect odorants in the amniotic fluid. The odor of amniotic fluid and complex flavor compounds like garlic, anise, alcohol, and carrot is transferred from the mother's diet and is selectively responded to by the preterm and term infant.<sup>11,13,14</sup> The duration of the exposure of the fetus to an odorant in the amniotic fluid and resulting postnatal behavioral effect varies but can be as short as 1 day. Odor memory can be demonstrated

immediately after birth and last for weeks or months. From a variety of studies, it is concluded that from late gestation, the fetus is able to detect, learn, and retrieve the information that was available in utero and use it to adjust to the transition to life outside the womb (see review by Schaal et al<sup>2</sup>). Whether the fetus has “learned” familiar odors during gestation or is predisposed to associating odor with experiences once born, there is clear evidence that there is continuity from fetal to



**Fig 3.** Olfactory receptor system.

newborn life, which contributes to species typical development and provides a foundation for the infant's attachment and socialization.<sup>1,13,15,16</sup> Familiarity with the mother's dietary intake lays the foundation for socialization and acculturation as the infant transitions into the cultural group to which the mother belongs via familiar dietary habits.<sup>10,13</sup>

## Newborn

Newborns communicate detection and discrimination of odor and taste through their physiologic and behavioral responsiveness. Arousal, head turning, mouthing movements, and motor movement toward the source of the sensory stimuli can be consistently elicited when the newborn is presented with odors and tastes. For example, olfaction has been shown to modulate states of arousal or sleeping behavior, to elicit emotional behavior, to approach and withdraw from specific sensory stimuli, to recognize particular individuals, and to communicate physiologic anticipation such as eating.<sup>2,10,17</sup>

At birth, infants make motor movements toward the mother's breasts to latch on and suckle.<sup>18</sup> They also "crawl" toward the familiar odor of their mother's breast pad.<sup>19</sup> Evidence of a "sensitive period" for olfactory sensory development has been defined to occur within the first hour after birth when there are high levels of circulating norepinephrine. Exposure to amniotic fluid and the mother's breast milk during this sensitive period influences later breastfeeding outcomes.<sup>16,20</sup>

Newborn infants prefer the odor of amniotic fluid and their own mother's breast milk to those of other lactating women.<sup>2,11,16</sup> It appears that the "Smellscape" of the mother's milk and glands in the areola of the breast provide specific volatile odorants not influenced by visual cues of looking at the high contrast of the areola on the breast to assist them with feeding.<sup>21</sup> Infants selectively turn their heads toward the breast, quiet from crying, and initiate mouthing movements in response to their mother's odor. These approach behaviors help to insure the survival of the infant by facilitating the protective and nurturing behaviors elicited in the mother and serve to establish the attachment relationship.

Responses of stable preterm infants resemble those of term newborns, indicating their ability to detect, discriminate, and indicate preferences among their odor environments.<sup>2,22,23</sup> In early studies, Sarnat<sup>24</sup> found that infants between 29 and 36 weeks gestation responded predictably to the odor of mint. Marlier et al<sup>22</sup> found respiratory changes upon exposure of preterm infants to two different odorants, indicating that preterm infants can both detect and discriminate between different odors as early as 28 to 29 weeks gestation. A variety of more recent studies have demonstrated that stable preterm infants respond to odors with physiologic reactivity, oral movements, head turning, gagging, and crying, to both low and high concentrations of odorants. Their physiologic reactivity may be greater than their behavioral activity, which may also be less vigorous than term infants. Sarnat's study of infants with perinatal asphyxia had decreased odor reactivity regardless of gestational age.

## Delivery, Postpartum, and Neonatal Intensive Care Unit Olfactory Experiences

The most essential implication for use of evidence in supporting the olfactory and gustatory sensory development of newborns is to provide supports for mothers and infants to be together early and continuously. Given our knowledge about sensitive periods and the need for support for the transition from fetal to newborn life, infants and mothers should be together for extended periods without removal of the infant from the mother's body.<sup>20</sup> The infant's mobility toward the odor stimulus of the breast should be supported without interruption for bathing, wrapping, or physical examination unless there are extenuating circumstances. Infants born at risk who need immediate medical and nursing care may benefit from being provided the smell of their mother's amniotic fluid and/or colostrum as soon as possible to enhance later odor identification and attachment relationships. Infants show reduced responsiveness to the mother's breasts when they have been washed.<sup>19,20,25</sup> Discouraging the washing of the mother's breasts, particularly the areola from where the most of the odorants emanate, will support the infant's arousal and behavioral responsiveness for feeding.

Skin-to-skin contact should be facilitated, supported, and encouraged as early and often as possible to provide multi-sensory, organized, and species typical support for the infant and physical and psychological adjustment for the mother. Odor of the amniotic fluid, skin, and breast milk of the mother should be readily available to the infant and not masked by soaps, detergents, or other odor containing products to provide specificity of the mother's scent to the newborn baby. Likewise, the odor of the baby should not be masked immediately after birth by bathing, odor-containing clothing, or other products to provide the mother with opportunities for identification of her baby, initiation of the attachment relationship, and psychological adjustment.<sup>12,19,26,27</sup>

If skin-to-skin opportunities are not possible due to illness of the mother or medical fragility of the infant, closeness of the mother and infant with as much skin exposure between the dyad as possible can be facilitated. Provision of the mother's smell with breast pads, handkerchiefs she has worn, breast milk on a cotton ball or cotton applicator, or other means of providing odor and taste input can facilitate recognition by the infant's mother at a later time and does not appear to be detrimental to the stability of the infant.<sup>28-30</sup> Instead, encouraging the mother to contribute her own unique scent that may influence the infant's well-being could provide much needed cognitive and emotional support during a stressful period of separation from her infant. The wearing of odors such as perfumes by staff can interfere with the infant's identification and response to their own mother's odor or to the appetitive behaviors to a feeding experience and should be avoided.

Provision of the odor and taste of the mother's milk has been shown to facilitate the infant's mouthing, sucking, arousal, and calming from irritability, especially in preparation for oral feeding.<sup>31,32</sup> For late preterm infants between 34 and 37 weeks who have difficulty arousing and being successful in

feeding, providing mother's odor and taste may facilitate feeding behavior. Similarly, for those infants who are fed by nasal or oral gastric tubes, which bypass the oral and nasopharynx, provision of a pacifier with tastes of mother's milk and the odor of her milk has been shown to increase nonnutritive sucking, intake, and growth and to shorten the length of hospitalization.<sup>33-35</sup> Provision of multisensory experiences such as combining odor and taste with proprioceptive and kinesthetic, visual and auditory input can potentiate sensory organization during feeding. Holding the baby close to the caregiver's body serves to provide this organized multisensory environment.

Many infants have difficulty with transitions that change the odor or taste sensory input. For example, changing from one formula to another or the addition of a new medication may cause adverse physiologic and behavioral responses. Providing a "bridge" through use of a familiar odor or taste might ease the transition.<sup>2</sup> Adding breast milk that the infant is familiar with to the formula or medication may avoid the reactivity that is apparent with abrupt changes.

Provision of a mother's odor or a familiar odor during invasive procedures such as heel sticks in term newborns has been shown to reduce reactivity and shorten the return to baseline.<sup>31,36</sup> However, more research is needed to determine the short- and long-term effects of provision of the mother's odor or taste through her presence during aversive procedures. Care is warranted when there are opportunities for the association of mother's odor with pain stimuli.

Infants can habituate to odor and taste if provided continuously and can be overstimulated if provided in too strong a concentration or in enclosed spaces. Attention to all sensory aspects of the infant's odor environment, including timing, duration and strength, and pairing with other salient cues, will go a long way to avoid effects on the organization of the olfactory bulb as well as on the learned behavior of the infant.<sup>2</sup> Selection of when, how long, and what intensity of odor or taste to be used should be carefully considered when planning for any introduction or use of odor or taste input. Monitoring for physiologic and/or behavioral response to the sensory input and immediate change should be made if the application shows detrimental effects. Similarly, individualizing the use of chemosensory input to the responsiveness, approach, avoidance, or arousal of the infant should be of primary concern.

## Implications for Environmental Olfactory Stimulation

The olfactory system detects low concentration volatile odorants, and the trigeminal system is sensitive to higher concentrations of chemical stimulants producing sensations such as tickling, stinging, burning, itching, or cooling and may affect respiratory stability.<sup>37,38</sup> Infants exposed to strong trigeminal stimulants such as disinfectants and detergents, alcohol, and other caustic liquids containing strong trigeminal effects showed decreased oxygenated hemoglobin over the

parietal region of the brain.<sup>39</sup> Because fetuses respond to trigeminal system stimulation in the first trimester, they may function with more sensitivity when prematurely born than at later stages of development.<sup>40</sup> Indeed, infants at risk (Apgar score <7) who were exposed to trigeminal stimulants had greater negative behavioral responses and variability than infants who were not at risk.<sup>41</sup> Respiratory rate decreases were stimulated by a smell of butyric acid,<sup>42</sup> and transitory respiratory arrest was seen in preterm infants after stimulation with a mixed olfactory/trigeminal stimulation.<sup>43</sup>

Awareness of potential strong odors, particularly in enclosed spaces such as incubators, and elimination of those odors from the infant's immediate bed space are essential. In incubators, odors have high volatility with the increased humidity and warmth, which may potentiate the odor and cause irritability and arousal. Attention to the potential of exposure to volatile odors and compounds in medical devices and equipment is warranted given the documentation of exposure of premature infants to high levels of phthalates. Infants hospitalized for extended periods in neonatal intensive care units are at especially high risk of exposure to as environmental contaminants such as those found in plasticizers used in medical devices.<sup>44,45</sup>

Provision of unfamiliar yet potentially soothing odor to infants in incubators have produced physiologic changes such as reduction of apnea.<sup>46</sup> Although there are too few data to make recommendations regarding the application of odors inside the incubator, it serves to increase awareness of the effect of odors in enclosed areas that can be detected by the infant.

## Conclusion

The expanding knowledge base regarding the development of smell and taste in fetuses and infants provides a foundation for understanding physiologic and behavioral responses in both term and preterm infants. Understanding the importance of continuity from fetal to newborn life for both the mother and infant informs practice in neonatal intensive care units. The chemosensory environment for newborns provides a dynamic yet primarily invisible foundation not only for physiologic stability and growth but also for early learning and social development. For the dyad, it provides "hidden regulators"<sup>47</sup> for the early attachment relationship between the mother and the newborn, insuring the protection, nurturing, nutrition, and the beginnings of intimate relationships. Recognition and support of the dyad's need for periods of extended, intimate, and organized experiences in appropriate chemosensory environments should be considered for all hospitalized infants.

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