Abstract
The first 1,000 days of life constitute an important period for the development of health and eating behavior. While the feeding mode drastically evolves, the child learns “how”, “what,” and “how much” food to eat. When orally exposed, infants discover food properties, with a variety of tastes, flavors, textures, as well as energy densities. Here, we focus on deciphering the involvement of taste and olfaction in the early establishment of eating behavior. In the OPALINE French birth cohort (Observatory of Food Preferences in Infants and Children), taste and flavor preferences were studied in relation to food preferences over the first 2 years. Both taste and flavor preferences evolved during this period. At weaning, a higher preference for sweet, sour, and umami tastes was associated with a higher acceptance of sweet-, sour- and umami-tasting foods, respectively. At 12 months, rejection of the odor of trimethylamine and dimethyl disulfide was related to the rejection of fish and sulfurous cheeses, respectively. Further, at 20 months, food neophobia was associated with odor but not taste differential reactivity, revealing the importance of olfaction in neophobic reactions. Further studies are ongoing to examine the long-term effect of early taste and flavor exposure on food preferences.

Introduction

Early childhood is an important period for the development of health. Recent researches using different approaches (experimental or epidemiological) have shown the importance of this early period for metabolic programming [1]. This
general concept of the “Developmental Origin of Health and Disease” (DOHAD) has been refined in humans to highlight the importance of the first 1,000 days for the development of health status [2]. In this context, our specific focus is on understanding how eating behavior is programmed during this period of the first 1,000 days. As a first observation, eating behavior undergoes a strong development during this period, in particular because the mode of feeding drastically evolves from conception until the age of 2 years. This implies that the child has to learn “how” to eat but also “what” to eat, “how much food” to eat, and “in which context” meals take place. After birth, when orally exposed to foods, infants discover their intrinsic properties, with a variety of tastes, flavors, textures, as well as energy densities, and all these aspects become even more salient at the onset of complementary feeding. By the end of the second year, food neophobia, i.e., the refusal of new food, develops [3–5]. We have previously observed that eating behavior established at the end of this period tracks on later into childhood and up to early adulthood [6–9]. Altogether, this calls for a better understanding of the driving factors and the key periods for the establishment of eating behavior during the first 2 years of postnatal life.

Here, we report several works in which we focused on deciphering the involvement of taste and olfaction in the early establishment of eating behavior over the first 2 years of postnatal life. We focused on both senses because they both strongly relate to the oral phase of feeding and because the chemosensory environment evolves strongly during this early period of life [10, 11]. In the frame of the OPALINE French birth cohort (Observatory of Food Preferences in Infants and Children), taste and flavor preferences were studied independently in children, as well as food acceptance and food neophobia over the course of the first 2 years of life.

Evolution of Taste and Odor Preferences in Early Life

At birth, previous works revealed evidence of differential preferences across tastes, with a preference for sweet taste, a rejection of bitter taste [12], and very little evidence of inborn flavor preferences (but rather of avoidance of smell of rotten foods [13]), except when infants had been previously exposed to specific flavors from the maternal diet [10, 11]. Thus, inborn taste and flavor preferences are not numerous although marked food preferences exist in adults and even in young children. It is then much needed to understand the factors contributing to the building of food preferences. The evolution of taste and flavor preferences at later stages in early childhood has received little attention. Within the OPALINE cohort, we studied longitudinally in a group of 285 infants the
evolution of taste preferences from 3 to 20 months [14, 15] and the evolution of
flavor preferences from 8 to 22 months [16].

Acceptance of each taste (sweet, salty, bitter, sour, and umami) and of a fat
emulsion relative to water was defined based on ingestion or liking at 3, 6, 12,
and 20 months of age [14, 15]. For each taste, 4 bottles were presented (water,
tastant, tastant, water). The acceptance of each taste relative to water was defined
using proportional variables that are ratios of ingestion or liking evaluated by
the experimenter. These data were analyzed with mixed models that accounted
for age and subject effects. Taste acceptance trajectories for all primary tastes
and for a fat emulsion were modeled. For saltiness, acceptance increased sharply
between the ages of 3 and 12 months. The trajectories of acceptance were par-
allel for sweetness, sourness, and the umami taste between 3 and 20 months,
with sweetness being preferred. Between 12 and 20 months, the acceptance of all
tastes, except bitterness, decreased, and at 20 months, only sweetness was not
rejected. The acceptance of bitterness remained stable. For the fat emulsion, ac-
ceptance evolved from indifference to rejection. Moreover, more rejections were
reported based on the judgment of the experimenter than of the infant’s liking.
Ingestion and liking ratios are rather complementary, and this result highlights
that a grimace is not necessarily associated with reduced ingestion.

Similarly, acceptance of each food odor was defined using proportional vari-
ables based on behavioral analysis [16]. Four control stimuli and 8 odors (4 rated
by adults as a priori pleasant and 4 as a priori unpleasant) were presented in bot-
tles to infants at 8, 12, and 22 months of age. The infant’s exploratory behavior
towards odorized and control bottles was measured in terms of mouthing defined
as a direct contact with perioral and/or perinasal areas. For each odorized bottle,
durations of mouthing were calculated relative to the control bottles. In this age
range, shorter durations of mouthing were found for unpleasantly scented bottles
(trimethylamine, dimethyl disulfide, and butyric acid) than pleasantly scented
bottles. So, between 8 and 22 months, unpleasant food odors lead to avoidance
behavior in infants, but pleasant food odors did not elicit specific behaviors.

In these studies, we noted that developmental changes were dependent on taste
and odor. We will now examine to which extent these developmental changes also
depend on the taste and flavor experiences the infant receives during this period.

Effect of Early Taste and Flavor Experiences on Taste and Food Preferences

Several pieces of work have shown that the flavors of the foods consumed by the
mother may be transferred into the amniotic fluid and the milk [17–19], but this
phenomenon is variable and not yet fully known [10, 11].
Nevertheless, the exposure to specific flavors in utero is associated to a higher attraction for the specific food odor at birth [17], to a higher acceptance of the specific food the infant was exposed to in utero when this food is offered at the beginning of complementary feeding [20], as well as to a higher acceptance of a similarly flavored food later in childhood [21].

In a similar fashion, the exposure to flavors in mother’s milk is associated to a higher acceptance of the specific food the infant was exposed to in mother’s milk when this food is offered at the beginning of complementary feeding [20] and to a positive effect of breastfeeding on acceptance of a new food, even in the absence of a specific flavor exposure [22]. This work suggests that the variety of flavor exposure in breast milk may be key and not only the specific exposure to a given flavor.

To expand this building knowledge on the effect of early taste and flavor exposure (i.e., dietary exposure to a variety of tastes in foods), in the OPALINE cohort we wondered about the effect of exposure to specific tastes in the context of milk feeding. It has been described that breast milk contains much more glutamate than formula milk, a compound that is associated with the umami taste. In this context, we observed that infants who were breastfed longer had a higher preference for the umami taste at the age of 6 months [23]. Moreover, concomitant with the introduction of complementary foods which are characterized by a variety of tastes, taste differential reactivity (within-subject variability across tastes; the higher the score, the greater is the difference in reaction of the infant to the tastes) clearly increased [14].

In order to develop our understanding of infant dietary taste exposure, we developed a method to evaluate the taste properties of the diet by describing extensively the intensities of the tastes of all the foods consumed monthly by infants relying on data from “food taste databases” [24]. The application of this method showed that the exposure of French infants to tastes was dominated by exposure to sweet taste over the first year, as illustrated in Figure 1 (in relation to the sweet taste of milk and a number of foods introduced after the initiation of complementary feeding) [25]. We expanded these findings by comparing the dietary exposure to sweet taste and fattiness [26]. They both increased during the first year in relation to the introduction of complementary foods in the child’s diet, but exposure to sweetness increases more rapidly than exposure to fattiness.

However, we have not shown any specific associations between dietary exposure to each taste and acceptance of each taste measured in water, as explained above [27]. The longer-term associations between early exposure to taste and further taste preferences are currently being explored in the OPALINE cohort.

Concerning olfactory exposure, we have found that at 8 months of age only, positive correlations were found between liking of some unpleasant odors and
Early Development of Taste and Flavor Preferences

Early exposure to these odors through the mother’s diet. However, no correlations were found between infants’ liking of the pleasant odors and early exposure to the foods bearing these odors. This study highlights that early exposure to unpleasant food odors may increase subsequent liking (or reduce subsequent dislike) of these food odors at least until the age of 8 months [28].

The originality of the OPALINE study was to evaluate the effect of early odor exposure on the infant through the mother’s spontaneous consumption of a wide spectrum of foods without asking mothers to consume one target food bearing a specific odor quality in sizeable amounts. Such “ecological” research regarding the influence of prenatal and dietary taste and flavor exposure on the establishment of preferences for foods with similar tastes and flavors is still in its beginning. More studies in different cultural contexts were the flavor experience is likely to be contrasted are needed to more completely understand these early imprinting phenomena.

**The Influence of Taste and Odor Preferences on Infants’ Eating Behavior**

To further explore the question of the association between taste or flavor preferences and food preferences, we further explored data from the OPALINE cohort. This was evaluated separately for taste and flavor.

Concerning taste, we characterized the taste intensities of all foods introduced at the beginning of the complementary feeding period. In parallel, mothers were asked to report their infant’s acceptance of these first foods. We applied

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**Fig. 1.** Dietary exposure of infants to the 5 primary tastes over the first year based on dietary data collected in the French OPALINE cohort (adapted from Schwartz et al. [25] with permission).
classification methods to the taste profiles of the foods, which showed that 15 groups of foods with similar taste profiles had been given to children (e.g., salty foods, sour foods, and sour and sweet fruits) [29]. Then, we compared the average acceptance of all food groups and showed that the acceptance of new foods varied according to their taste profiles. More specifically, we showed that the acceptance of salty vegetables was higher than the acceptance of bitter vegetables, or of sweet and bitter vegetables [29]. Furthermore, we showed that a higher preference for sweet, sour, and umami tastes was associated to a higher acceptance of some sweet-, sour- and umami-tasting foods, respectively [29]. This supports the hypothesis that the preference for some foods was partly related to the specific preference for their taste properties. Finally, an exploration of the factors related to vegetable acceptance along the first 2 years showed that a higher bitterness acceptance was associated with a higher acceptance of vegetables at the age of 1 year [30].

Concerning flavors, we similarly explored the acceptance of foods bearing specific odors and evaluated whether their acceptance was related to the acceptance of the corresponding odors (presented alone in scented bottles). We found that at 12 months rejection of the odor of trimethylamine and dimethyl disulfide was related to the rejection of fish and sulfurous cheeses between 12 and 15 months, respectively [31]. Therefore, in the case of olfaction, the flavor-food acceptance associations concerned foods with strong, unpleasant flavors at 12 months only, suggesting that the olfactory system acts as an “alarm” system during this period of food transition.

Eating behavior in children is characterized by its evolution as far as food neophobia is concerned. By the end of the second year, neophobic reactions start happening and can also be designated as picky eating behavior. This developmental phase concerns most children, but we were interested in evaluating whether neophobic reactions could be related to differences in taste and smell acceptance. To evaluate this aspect, we considered taste differential reactivity by computing within-subject variability across tastes as well as flavor differential reactivity by computing within-subject variability across flavors. We found that at 20 months, food neophobia was associated to flavor differential reactivity but not to taste differential reactivity [32], stressing the importance of olfaction in the development of neophobic reactions.

Finally, we have developed a working model of chemosensory, experiential, and environmental factors likely to influence food likes at the age of 2 years (Fig. 2). In this model, we included parental feeding practices and feeding style in the environmental and experiential factors likely to influence likes. The evaluation of this model showed that most of the factors hypothesized to influence liking for vegetables at the age of 2 years had a
Conclusions

It was shown that children are born with the ability to taste, smell, and discriminate foods, and also to learn to like a new food and its sensory properties. However, marked reactions to taste and olfactory inputs may hinder the learning processes and may be associated with the rejection of specific foods with pro-

significant influence, but not the variety of early flavor exposure (in utero and in mother’s milk), when all factors are taken into account in the same model [30].

Fig. 2. Working model of the various early factors which are likely to influence the development of food likes at the age of 2 years. Among the putative factors, it was previously shown that exposure to food-related flavors (in utero or in breast milk) may impact acceptance of new foods at the time of onset of complementary feeding (CF), because the amniotic fluid or breast milk may be flavored by the flavors from the mother’s diet. The reactivity of the infant to sensory stimuli, in particular food-related tastes and odors, is also likely to modulate his/her acceptance of new foods. At the onset of CF, repeated exposure to a given food was shown to strongly impact its acceptance; moreover, exposure to a variety of foods within a given category impacts the acceptance of other new foods from this category. Tracking of eating habits was previously shown but did not necessarily cover well the very early period. Finally, beyond the impact of the family feeding practices, it was previously shown that parental feeding style is also likely to impact food likes in young children.
nounced tastes and/or flavors. Through the effect of eating experience, taste and olfactory cues acquire a biological significance in relation to the foods they are associated with. Observation of the development of taste and flavor preferences in children shows that learning abilities are high between the onset of complementary feeding and the age of 2 years. This period clearly appears as a window of opportunity to introduce foods from the family diet, particularly vegetables. Learning processes also happen in interaction with parental feeding style and practices, which have to be taken into account to fully understand the development of children’s eating behavior. The research on the early development of food preferences in relation to taste and flavor exposure is still in its infancy. Much more has to be learned: the type of exposure that is more likely to alter food preferences further, the most important periods for this chemosensory exposure, and the conditions under which they may resist to the influence of other factors which are also likely to influence the development of eating behavior and food preferences.

**Practical Implications**

The present results may have practical implications in terms of child feeding in the early years. Encouraging mothers to eat a variety of foods during pregnancy may help to imprint their child’s liking of healthy foods through the exposure to the flavors of such foods in utero. Similarly, breastfeeding until the start of complementary feeding may enhance the acceptance of new foods offered at this transitional stage in child feeding. Parents should also be aware that when tasting or smelling new foods, children are more likely to display negative facial expressions than positive ones, but they may also continue eating. Thus, parents should be encouraged to continue offering new foods to their children for sensory learning to take place, even if they feel that their child’s initial reactions to these foods are not very positive. Such advices should be particularly enforced in parents of children who are very sensitive to taste and odors, and who may be more likely to display neophobic reactions. Parents should be patient and ready to persist in their willingness to offer new foods without forcing their child to eat.

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