

Review

Early Influences on Development of Sensory Perception and Eating Habits



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ABSTRACT

Infancy and early childhood are important periods for the development of food choices and eating preferences that are tracked into adult life, influencing weight gain, body composition, and metabolism and ultimately affecting the balance between health and disease. In this narrative review, we discuss studies focused on the effects of fetal programming and early food experiences, highlighting recent advances in the discovery of factors that contribute to the development of food preferences and eating behavior. Food preference can be influenced by early direct contact with flavors, textures, and aromas, as well as by environmental adversities during early development. Evidence suggests that exposure to intrauterine growth restriction is associated with increased preferences for highly palatable foods, such as those rich in carbohydrates and fats, over the life course. Early flavor experiences, whether from amniotic fluid or human milk, may also shape the development of food preferences. Finally, children are more likely to accept textures that they are able to manipulate, and early exposure to a range of textures facilitates the acceptance of foods of various textures later on. Improving dietary habits during gestation (fetal) and postnatal periods is of critical importance for the establishment of positive eating habits and healthy growth in infants and should be an important focus of primary prevention efforts.

Keywords: food preferences, childhood, obesity, eating behavior

Statement of significance

Our narrative review provides a thorough and comprehensive evaluation of how early food experiences may shape the development of food preferences later in life. The perinatal period is crucial for the establishment of positive eating habits and healthy growth and should be a focus of primary prevention efforts.

Introduction

Fetal life and early infancy are critical periods for the establishment of healthy dietary habits, during which food preferences are formed and tracked into childhood and beyond [1,2]. Infants show considerable plasticity in preferences, enabling them to accept and learn to prefer foods that are available within their particular cultural environment and socioeconomic status [3]. Some researchers indicate that there may be a sensitive period in

the first year of life when children are more receptive to new food flavors and textures, suggesting that delaying the introduction of solid foods may lead to feeding difficulties in later childhood [4].

Most published research has focused on parental feeding practices and food neophobia during childhood [5–8], but the influence of in utero conditions and first feeding experiences during infancy has been less thoroughly addressed in the literature. This period is particularly important because taste and olfactory systems are capable of detecting flavor information

Abbreviations: HPVS, Healthy Plate Variety Score; IUGR, intrauterine growth restriction.

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prior to birth, through the amniotic fluid in utero and then later through milk feeding [1]. There is evidence that this early flavor exposure may have rather different effects on food acceptance than those seen in later childhood [9–11], which could ultimately reflect on later child diet and weight outcomes [12].

Food texture is one important component of food acceptance, often neglected in studies. It has been suggested that early infancy is a sensitive period for food texture exposure, and delaying introduction of solid foods may lead to later childhood aversion to certain textures [13], and a preference of liquid over solid textures is potentially linked to overeating [14]. Once established, these feeding habits can be carried on to later childhood [15] and adult life [2]. In addition, food texture plays a key role on the development of oromotor skills and the masticatory apparatus [16].

Several studies have shown that weight gain during infancy may have long-term consequences on health [17]. Rapid growth that follows early growth retardation has been associated with increased risk of overweight and obesity in children, and differences in weight gain during early infancy are at least partly explained by means of infant feeding [18,19]. Therefore, it is of primary importance to develop effective evidence-based strategies to promote the development of healthy eating styles.

This narrative review aimed to synthesize current clinical and experimental evidence of the effects of fetal programming and early food experiences on the development of food preferences and eating behavior during infancy and early childhood. Considering 1) the paucity of studies focusing on the influence of in utero conditions and very early eating experiences on food preferences and eating behavior, 2) the lack of consideration of early food texture exposure as an important factor influencing eating habits, and 3) the long-term health consequences of early childhood growth and weight gain, we wrote this narrative review for integration of this broad theme that ultimately arises from a range of different areas. We have reviewed related topics in the past, but the latest review is almost one decade old [20], and the field has progressed considerably since then. Therefore, here we focused on recent advances in this topic during the last 10 y, although classic studies were also incorporated. We also acknowledge that here we used the terminologies “breastfeeding”/“breast milk” because they are widely used in the literature. However, in times of transition toward a more adequate and nongendered language, alternative expressions could include chestfeeding/chest-fed/human milk.

Effects of in utero conditions on eating preferences

Children’s eating behavior is modulated by a complex interplay of genetic and environmental factors [21]. Evidence suggests that food preferences may be affected by events happening long before infants are introduced to foods, during the prenatal period [20]. Brain development during fetal life is a wide-open opportunity for the establishment of programming effects, and the exposure to adverse events in utero may have an impact on eating behaviors.

In fact, some studies show that chronic diseases during gestation (hypertension, diabetes), exposures (tobacco smoke, drugs), and malnutrition (undernutrition or overnutrition) may result in intrauterine growth restriction (IUGR), a situation in which the fetus does not reach its full growth potential during pregnancy [22].

Impaired fetal growth can drive the individual to prefer specific foods during the life course, a process called the “thrifty-eating” phenotype [23]. For growth-restricted individuals, the general environmental message transmitted during pregnancy is a possible shortage of nutrients in postnatal life. Thus, environmental factors during early development may induce a series of adaptive physiological responses favoring energy storage to improve short-term fetal survival [24]. Nevertheless, considering the large availability of energy dense, palatable, and ultra-processed food in the actual global environment, the thrifty phenotype becomes a risk factor for increased adiposity, diabetes, and cardiovascular disease in the long term [25,26].

It has been demonstrated that infants born small for gestational age have a less healthy dietary intake than those born with appropriate gestational age. Perälä et al. [27] observed that a small size at birth is associated with a lower consumption of fruits, berries, and rye products in adults aged 56 to 70 y. Furthermore, the authors found a positive correlation between size at birth and increased consumption of fats, as well as a lower intake of carbohydrates, sucrose, fructose, and fiber. Corroborating these findings, another study showed that adults born preterm at very low birth weight consumed less fruits, vegetables and berries, and dairy products than individuals born at term [28]. Moreover, Ayres et al. [29] showed that intrauterine growth strongly correlates with the hedonic response to a sweet solution in preterm infants in their first day of life.

Despite the evidence suggesting that both low and high birth weight children have increased risk for obesity and related diseases in adulthood [30,31], few studies have explored the effects of being born large for gestational age on food choices later in life. Eloranta et al. [32] found that higher birth weight is associated with lower consumption of fruit and berries, higher energy and sucrose intakes, and lower fiber intake in children at aged 6 to 8 y. However, it is important to consider that this relationship is complex and subject to confounding factors; according to the results of a longitudinal study, higher birth weight children ate less energy-dense food at age 4, possibly because parents may be more restrictive of their children’s caloric intake because they were born heavier than the populational standard [33].

Evidence also suggests that birth weight is associated with altered dietary intake in childhood in a sex-specific manner. A study pointed out the impact of birth weight on childhood obesogenic behavior across the sexes, showing that physical activity and screen time presented a U-shaped association with birth weight in boys, while physical activity had an inverted U-shaped association in girls [34], and low birth weight girls/women seem to be more vulnerable to the effects of fetal programming of food preferences [23,35]. However, other studies have shown that boys born with lower weight are more likely to have higher energy-dense intake [36]. Similar findings were also demonstrated in a study in which birth weight was inversely associated with diet quality in boys but not in girls [32]. One possible explanation for these sex-specific differences in dietary patterns are the differences between boys and girls at the neurological and biological levels, especially in terms of timing at adiposity rebound, puberty, and body composition [37], which can consequently influence eating patterns [38]. Hence, fetal programming seems to alter eating behaviors of both sexes when compared with controls, but the timing and nature of the differences can vary between the sexes during development.

Proposed mechanisms linking in utero conditions to food preferences

A potential mechanism linking early life conditions to an individual's food choices and postnatal metabolic risk is alterations in the brain circuitry related to palatable food intake and energy expenditure. An experimental study showed that IUGR rats exhibit a preference for palatable foods, potentially due to alterations in their mesolimbic reward pathway functioning, as evidenced by altered levels of tyrosine hydroxylase phosphorylation and dopamine D2 receptor levels in the nucleus accumbens [39]. In agreement with these results, Laureano et al. [40] found a delay in the peak dopaminergic accumbal response to sweet foods in fetal food-restricted adult rats compared with controls. The increased intake of palatable foods observed in food-restricted rats can be considered an attempt to reach the same dopaminergic response in a similar interval of time as in control rats. This knowledge was deepened in a recent study showing that IUGR female rats are more impulsive in a task that involves a delayed food reward due to changes in the dopamine signaling in both the medial prefrontal and orbitofrontal cortex [41]. In addition, Silveira et al. [42] also observed that variations in a genetic score reflecting dopamine signaling capacity are positively correlated to spontaneous sugar intake only in IUGR children, reinforcing the role of dopamine function in this behavioral feature especially in individuals exposed to prenatal growth retardation.

The compilation of these results demonstrates that the fetal programming of food preferences is a consistent finding. One important point to consider is that most of the studies reviewed used only low birth weight as a marker for poor intrauterine conditions [36,40,42]. Despite birth weight data being a powerful predictor of an individual newborn's survival, several other factors can also impact an infant's development. Such factors include parental mental health, socioeconomic status, domestic violence/sexual abuse, marital strain, as well as maternal smoking [43,44]. Therefore, future studies should investigate the prenatal environment in a broader sense, considering the cumulative impact of multiple factors that affect eating behavior.

However, stressful events during pregnancy may not necessarily be reflected in birth weight but might lead to important changes in fetal development. This means that not all fetuses that have failed to meet their growth potential are classified as low birth weight as per a specific standard or cutoff. Similarly, not all fetuses that are born with low birth weight are pathologically growth restricted. Because IUGR is a dynamic process, the ideal study design would include repeated ultrasound fetal measurements to adequately define a failure to achieve full potential growth and exclude other causes of low birth weight (i.e., constitutional). So far, little is known about the role of catch-up growth in the programming of feeding preferences. Larger birth cohorts, with appropriate IUGR definition and prospective long-term follow-up, may further clarify the relation and causality of these findings.

Influence of amniotic fluid on gustatory sensitivity and later food preferences

Vital for food intake and homeostasis maintenance, eating behavior is determined by the interaction between many different factors including food enjoyment, which has been

referred as one of the main drivers of food consumption [45]. At birth, infants exhibit an innate predisposition to like sweet and salty flavors and to dislike bitter and sour tastes [46,47]. It has been hypothesized that taste is an important protective sense [48] and this predisposition may favor the consumption of energy-dense foods (sweet taste) while avoiding the ingestion of poison and toxins (bitter taste) [49]. However, children show considerable plasticity in their preferences, enabling them to accept and learn to choose foods that are accessible within their particular cultural environment [1]. In this context, flavors provided by amniotic fluid and human milk and/or formula can be considered a primary influence on gustatory sensitivity and later food preferences by infants. A systematic review [50] showed that flavors from the maternal diet are present in the amniotic fluid as well in human milk, and those flavors are detectable by the fetus or infant. In addition, the review found that prenatal flavor exposure was related to greater acceptance of flavor-related foods later in life. In utero events may affect taste and flavor preferences later in life, modulating long-term nutrient intake and, consequently, later health [51].

It is well accepted that the initial step in flavor perception occurs with fetal swallowing of amniotic fluid [10]. By the last trimester of prenatal development, taste buds and olfactory receptor cells can detect and communicate information to central nervous system structures. As a result, fetuses are capable of detecting changes in the flavor of amniotic fluid transmitted during pregnancy as a function of the mother's food choices [52]. Ethanol is especially interesting, as the substance has teratogenic properties and is involved in deleterious morphological and neurobehavioral consequences [53,54]. Faas et al. [55,56] conducted 2 experiments to investigate if there were changes in the behavioral response of children exposed to frequent alcohol drinking patterns during pregnancy in comparison to children with infrequent exposure. They observed more head and facial movements in infants 1 to 2 d old [56] and a longer duration of aversive responses and higher frequency of appetitive responses in infants 7 to 14 d old exposed to frequent alcohol drinking patterns [55].

Animal studies involving manipulation of the fetal environment and introduction of an apple solution directly into the amniotic fluid demonstrated that offspring exposed to the apple solution in utero showed an increased preference for apple during the postnatal period [57,58]. However, based on these studies, it is not clear how the fetus is naturally exposed to such flavors in utero. Hepper [59] clarified this question by conducting an experimental study whereby the fetus was exposed to chemosensory stimulation by feeding pregnant females garlic during gestation. In this study, Hepper reported that offspring of dams fed garlic during gestation displayed a significantly greater preference for garlic than offspring of dams not fed garlic during gestation.

In humans, relatively few flavors have been detected in amniotic fluid to date. Hepper et al. [60] demonstrated that in cases of a regular consumption of foods containing garlic during the last part of the pregnancy, infants were able to detect garlic between 15 and 24 h after birth by orienting their heads toward a cotton swab containing garlic more than infants in which there was no consumption of garlic during pregnancy. In addition, Schaal et al. [61] compared behavioral measures of attraction to anise odor in infants exposed to anise flavor through the diet

during pregnancy. According to the results, infants born from anise-consumers had a preference for this odor at birth and 4 d later compared with infants without prenatal exposure. Although these studies demonstrate prenatal learning through exposure in the intrauterine environment, the influence on subsequent food acceptance in later childhood is not well established. The only study that has found an association between intrauterine exposure and later preference, showing that prenatal garlic exposure predicts consumption of a gratin containing garlic at 8 to 9 y, does not control for the interim exposure period and, hence, this evidence does not support the long-term effects of prenatal flavor exposure [60]. However, studies focusing on general aspects of the diet, such as variety and healthy quality, suggest that there is a correlation between the diet consumed during pregnancy and the children's diet. Jones et al. [62] developed the Healthy Plate Variety Score (HPVS), an index that assessed dietary variety against 5 food groups and applied it to mother-child dyads from both an English (Avon Longitudinal Study of Parents and Children, ALSPAC) and a French (EDEN) cohort. They found a positive association between HPVS scores during pregnancy and children's HPVS scores at all ages. Okubo et al. [63] collected dietary information from 758 Japanese mother-child pairs and used a cluster analysis to identify dietary patterns. They found 2 patterns, one characterized by "fruits, vegetables and high-protein foods," the other "confectionaries and sweetened beverages" in infants 16 to 24 mo old. Infants whose mothers had the "fruits, vegetables and high-protein foods" pattern were less likely to belong to the "confectionaries and sweetened beverages" pattern themselves. A similar study was conducted by Lioret et al. [64], analyzing the dietary patterns of 421 Australian mother-child pairs when the infants were 3 mo of age. The study describes that the association between maternal educational background and a balanced infant weaning diet was mediated through the patterns of maternal consumption of fruits and vegetables. Ashman et al. [65], working with a relatively small Australian cohort, suggests that the indirect effect of maternal pregnancy diet on child diet was mediated through maternal postnatal diet, particularly for fruit and vegetables.

Influence of breastfeeding on early food preferences

The development of flavor perception continues when the infant is exposed to human milk, a liquid that, like the amniotic fluid, comprises flavors that dynamically reflect the mother's diet between nursing episodes and even *within* the same nursing episode [9,66]. Several flavors are known to be transmitted through human milk, including garlic [67], carrot [11], ethanol [68], vanilla [69], and cigarettes [70], among others. Hausner and colleagues [71] demonstrated that volatiles from the diet are transferred selectively and in relatively low amounts. Kirsch et al. [72] showed that lactating women who ingested capsules containing 100 mg 1,8-cineole (eucalyptus) had a detectable presence of the substance in their milk, although there was high interindividual variability. However, there are reports that not all flavors consumed during lactation are transmitted to human milk, for example *n*-3 fatty acid-enriched fish oil capsules [73] and fennel-anise-caraway tea [74]. Those studies had very small sample sizes though, ranging from 8 to 23 lactating women.

There is some evidence that the consumption of specific flavors during lactation, when transmitted to human milk, may

increase infant acceptance of these flavors in the short term. In one study, infants whose mothers were randomly instructed to consume carrot juice during the third gestational trimester or during the first 2 mo of lactation consumed greater amounts of carrot-flavored cereal and showed fewer negative facial responses to the intake of carrot at ~6 mo of age compared to infants whose mothers drank water during pregnancy and lactation and avoided carrots [11]. It has been also demonstrated that the longer the breastfeeding duration, the more infants accepted the umami solution at 6 mo, perhaps due to higher glutamate content of human milk compared with formula milk [75]. Some researchers, however, suggested that breastfeeding *per se*, rather than learning from specific flavor exposure, facilitates acceptance of a novel flavor. The authors state that this effect is due to the daily flavor variation in humans milk experienced by breastfed infants [76]. Indeed, Hausner et al. [76] reported that breastfeeding facilitates the acceptance of novel flavors, and the positive effect of breastfeeding on food acceptance may be limited to the very beginning of the new food exposure. Acceptance learning was observed in formula-fed infants, which corresponds to flavor-specific acceptance learning [76].

However, formula-fed infants have a considerably different early flavor experience from those fed with human milk. Usually, infants who are exclusively formula-fed receive the same type of formula on a daily basis, for weeks, which limits their exposure to varied flavors [77]. Previous studies have shown that formula-fed infants also show preferences for the flavors experienced during formula-feeding. Compared to infants fed bovine milk-based formulas, those fed hydrolyzed casein formulas consumed greater amounts of savory, sour, and bitter-flavored cereal and displayed fewer facial expressions of aversion during feeding [78]. As hydrolyzed casein formulas are described as having pronounced bitter, sour, and savory tastes, infants who are regularly fed formulas that contain casein hydrolysate have more experiences with these tastes and flavor qualities. Mennella and Beauchamp [79] suggested that these preferences extend beyond weaning because taste preferences of children aged 4 to 5 y varied as a function of the type of formula they had consumed earlier in life. Specifically, children fed protein hydrolysate formulas during infancy were more likely to prefer a sour-tasting apple juice than children fed bovine milk-based formulas and were also more likely to preferentially consume broccoli, which has flavor notes similar to protein hydrolysate formulas. Overall, these studies showed that exposure to formula flavors affects children's acceptance of foods later in life, but those flavors must be part of the family's diet, otherwise children may not benefit from this early imprinting [52]. As formula-feeding may be required for many infants when human milk is not available, more studies are needed to establish effective ways of increasing flavor exposure in formula-fed infants. For example, it is still unknown if routinely switching formulas or increasing flavor profiles of the prominent formula (e.g., by adding anise or cinnamon) can benefit food acceptance of various foods in formula-fed children.

Studies have shown that breastfeeding duration is positively associated with food acceptance later in childhood [80,81]. However, it is not clear what the mediator variable in this process is, if the benefits are exclusively due to the consumption of human milk or due to the act of breastfeeding, and whether

confounding factors such as socioeconomic status and educational level have been adequately controlled [82]. Families who have more healthy attitudes toward feeding, who are of higher socioeconomic status and education, may breastfeed longer and place more emphasis on introduction and exposure to a healthier dietary pattern [83,84]. Nonetheless, there are few controlled studies that found that the effects of breastfeeding on acceptance and preference for fruit and vegetables remained over time [12, 85,86]. In an analysis of 4 European cohorts of children aged 2 to 4 y living in the United Kingdom, France, Greece, and Portugal, longer breastfeeding durations predicted higher fruit and vegetable intakes during later childhood, even after adjusting for maternal dietary intakes and relevant sociodemographic variables [86]. Using secondary data, Rose et al. [12] observed that formula-fed infants at 5 mo showed higher sugar-sweetened beverage intake and fewer fruit and vegetable intake at 6 y than breastfed infants, even after controlling for potential confounders such as demographics (race, education, marital status, among others) and birth weight.

Another important advantage to exclusive breastfeeding that is not always considered is its positive effect on the development of the orofacial musculature, which can ultimately affect a child's food acceptance. Children who are nursed at the chest present a markedly different pattern of sucking, with greater facial and masticatory muscle activity than those who are bottle-fed [87,88], as observed by electromyographic analysis comparing breast- and bottle-feeding [89]. During breastfeeding, the child is forced to drink human milk through a squeeze action with the movement of lips, tongue, and mandible, whereas for children who are bottle-fed, the movement for obtaining the milk is more passive and effortless [90]. One of the muscles that actively participates in breastfeeding is the same muscle that will further (from the age of ~6 mo onward) carry out mastication, as its name suggests – the masseter. Supporting this idea, Pires et al. [16] found a positive correlation between the duration of breastfeeding and masticatory function in preschoolers. In their study, children breastfed ≥ 12 mo showed higher scores across all tested parameters, but particularly on the masticatory pattern and masticatory movement parameters, which are the most strongly influenced by breastfeeding due to their close association with the development of the masticatory muscles. Even though this subject has been little investigated, the appropriate orofacial development favored by breastfeeding may contribute to children's dietary preference toward foods with a harder texture, such as fruits and vegetables [85]. In this sense, Marquezin et al. [91] observed a close relationship between bottle-feeding and the texture of the food ingested in later infancy. More experimental studies are necessary to better understand the impact of breastfeeding on masticatory function development and food acceptance during childhood.

In addition, previous reviews on the association between infant feeding and later obesity suggest a small, but protective, effect of breastfeeding initiation and duration [92,93]. Although the mechanisms by which infant feeding influences weight gain or obesity in later life are unclear, one possible explanation is that breastfeeding provides the infant with greater opportunity for self-regulation of intake by reaching satiety earlier, thus matching their energy needs. As previously mentioned, infants who are bottle-fed can obtain milk with less effort than from the chest, in a more passive process with fewer opportunities to

control the amount consumed, facilitating overfeeding. Supporting this idea, a longitudinal study showed that infants who are bottle-fed in early infancy are more likely to empty the bottle or cup in late infancy than those who were breastfed, possibly because of their reduced ability to self-regulate milk intake [94]. Nevertheless, one limitation of this study was that the sample underrepresented families from low socioeconomic levels. Thus, additional longitudinal studies with adjustment for confounding factors are still needed to better understand the association between being breastfed and the development of obesity later in life.

During early infancy, breastfeeding is associated with healthier growth patterns. Abraham et al. [80] showed that breastfed babies are less likely to have overweight or obesity at 4 y than formula-fed babies. Imai et al. [95] found that infants who were fed solid foods along with formula-feeding prior to 6 mo of age had faster growth during infancy and greater BMI at 6 y of age compared to exclusively breastfed infants. To better understand the impact of health promotion strategies on growth and prevalence of overweight and obesity in children at preschool age, Schwartz et al. [96] performed a randomized clinical trial testing a pro-breastfeeding and healthy complementary feeding intervention in a sample of adolescent mothers and maternal grandmothers. While the intervention prolonged the duration of exclusive breastfeeding and delayed the onset of complementary feeding, the researchers found no impact on growth or prevalence of overweight at age 4 to 7 y. Bell et al. [19] showed that formula-fed infants gained weight more rapidly than breastfed infants. Formula-fed infants also gained weight out of proportion to their linear growth, translating to progressively increasing BMI z-scores over time. However, this excess weight gain did not represent an excess gain in adiposity; instead, it reflected progressively greater gains in lean mass throughout the first 7 mo of life [19]. Previous studies have also investigated if the type of formula can influence growth patterns. The weight gain from ages 2.5 to 7.5 mo in infants fed an extensively hydrolyzed protein formula was more normative than that of infants fed cow milk formula [10]. Contrary to these findings, an epidemiological study did not find a significant impact of type of formula used and growth at 4 mo [97].

In sum, and considering the evidence available, early flavor experiences, whether from amniotic fluid or human milk, may shape early food preferences; thus, efforts to stimulate the consumption of healthy and varied diets during pregnancy and lactation might be an important focus for primary prevention. In contrast, infants fed formula learn to prefer its unique flavor profile and may have more difficulty initially accepting new flavors. However, a seemingly unexplored possibility is the evaluation of feeding strategies composed of a range of different flavors and/or variety of formulas that might be used for primary prevention as well. Also, breastfeeding and/or human milk intake seem to be associated with healthier growth trajectories during childhood, emphasizing the importance of counseling and support for breastfeeding and use of human milk whenever possible and not contraindicated.

Effect of food texture on feeding skills development and food acceptance

At birth, babies have the ability to process liquids that only require the suckling and swallowing functions. The movements

of the tongue, lips, and mandible are synergistic and undifferentiated [98]. To the extent that their oromotor skills have developed and with the emergence of their first teeth, infants are capable of processing and thus accept soft solids by around 6 to 7 mo of age [99]. Changes in efficiency in feeding skills occur simultaneously with the transition from munching to chewing. This process is characterized by the transition from up and down movements of the jaw during munching to diagonal and lateral movements to ultimately reach a circular rotary movement [100]. In addition, tongue movements increase in complexity, from shifting and rolling movements to lateral movements, enabling infants to transfer the food to the surface of the molars [101].

Oromotor skill improvement occurs simultaneously with a child's general development (coordination, posture, psycho-emotional development, etc.) and influences the acceptance of different types of food [102–104]. Table 1 shows a summary of the skills acquired according to the age of the child during normal neurodevelopment, which corresponds to the transition from one type of food to another [105]. It traces an important parallel between other domains of neurodevelopment (e.g., fine and gross motor skills, language), the oral abilities, and the capacity to handle different textured foods and manipulate different eating instruments. This evaluation of the child and their eating abilities in the context of their global neurodevelopment is crucial for family counseling and reassuring. This understanding enables the primary care physician to provide sound guidance to parents and caregivers and establishes a framework for managing complex feeding problems.

Compared to other sensory characteristics of foods such as flavor, less information is available about infant perception of food texture and its influence on food preference. Werthmann et al. [106] carried out a study to test experimentally which food sensory properties influence food acceptance and found that the texture, but not color or taste, of the offered yogurts affected food acceptance in young children. The authors also hypothesized that gradual exposure to changes in texture can possibly help to overcome picky eating behavior. These findings were also supported by parental reports that texture affects food preferences in children [107].

Evidence suggests that the improvement of chewing skills through texture exposure can lead to an enhanced preference of food with harder textures. Focusing on the effect of food texture on chewing duration of children between 6 mo and 2 y of age, Gisel observed that as children get older, they became more efficient at mastication, and chewing time decreased for different textures of food (solid, viscous food and purée) [108]. Although chewing efficiency continues to increase until 24 mo of age, the

most marked changes in oral skills occur between 6 and 10 mo, when the infant is capable to chew more solid textures [108]. This pattern of texture acceptance was recently supported by Demontei et al. [109], who longitudinally assessed the evolution of food texture acceptance and feeding behaviors between 6 and 18 mo. In this study, from 6 mo onwards, purées and experimental infant foods were highly accepted, whereas the acceptance of sticky textures (fork-mashed banana and cheese) increased significantly from 8 mo. Between 6 and 8 mo, all food textures are processed mostly by sucking, and masticatory movements are rare. The most marked changes in feeding behaviors occur between 8 and 10 mo with the strong development of chewing movements and a decrease in sucking behaviors. As expected, hard textures (infant biscuit and crusty bread) are well accepted from 12 mo and raw pieces from 18 mo, coinciding with the emergence of chewing behavior. Furthermore, a pilot intervention study showed that changing the texture of commercial infant foods offered to 8-mo-old infants for 4 wk can have an impact on the infant ability to chew solid foods. After the 4-wk exposure period, infants that had been exposed to the foods with larger and harder pieces showed a significantly higher chewing capability scores for the pieces requiring chewing (carrot and potato), but not for a piece of banana or for mashed foods [109]. Meanwhile, there is the impact of early introduction of solid food, i.e., before the recommended 4 to 6 mo of age [110, 111]. Daniels et al. [112] investigated the association between obesity risk and timing of solid food introduction in a narrative review covering 1990 to 2013. They concluded that early introduction, prior to 4 months, may result in increased risk of childhood obesity [112].

Food texture also plays an important role for the correct development of orofacial growth, wherein decreased masticatory demands due to liquid or soft diets may cause impairments of the craniofacial growth and maturation of masticatory musculature [113]. An experimental study demonstrated that a liquid diet after weaning is related to impairment of motor performance of the jaw and tongue muscles, including more irregular chewing rhythms, shorter chewing sequences, and longer chewing cycles [114]. In Japan, children who liked hard foods such as cabbage and celery showed higher bite force and higher occlusal contact area than those who disliked these foods. Moreover, Little et al. [115] investigated the secular changes in craniofacial dimensions among indigenous children in an isolated community in Mexico between 1968 and 2000 and found that changes in the cephalic index and cranium over time can be explained by a decrease in food (maize) coarseness or grit content. Therefore, it seems that the development of both the masticatory apparatus and feeding skills depends on texture exposure.

TABLE 1
Feeding ability and other developmental capacities according to the age of the infant.

Capacities	0–2 / 3 mo	3–6 / 7 mo	7–10 / 11 mo	11–15 / 16 mo	16–24 mo and more
Feeding (oral motricity)	Head movement	Suck/bite	Chew	Masticate	Masticate well
Food texture (sensory responsiveness)	Liquid	Purée	Mashed with soft lumps	Chopped into pieces	Table food
Instruments	Chest/infant bottle	Spoon	Cup/fingers	Eat alone	Fork
Language	Cooing	Babbles	Detached sounds	Detached words	Associated words
Fine motor skills	Arm wiggle	Captures/holds	Transfers	Releases/throws	Scribbles
General motricity	Head up	Rolls	Sitting no support	Standing/walking	Runs/hops

Adapted and translated from Ramsay 2001 [105].

The capacity of infants to cope with textures was also found to be dependent on the textures previously offered to them [13]. Some research indicates that there may be a sensitive period in infancy for the acceptance of new food textures, suggesting that delaying the introduction of solid foods may lead to an aversion to certain textured foods and possibly feeding difficulties in later childhood [13,15,116]. Blossfeld et al. [13], who evaluated 12-mo-old infant's acceptance to pureed and chopped carrots, showed that infants consumed significantly more of the pureed carrots than the chopped carrots. The strongest predictor of the acceptance of chopped carrot at 12 mo, besides the presence of teeth, was previous experiences with textured foods. Furthermore, longer duration of breastfeeding was related to higher variety in the diet and greater appreciation of chopped carrot. Along the lines of the studies from Mennella et al. [11] and others, the authors suggest that enriched early flavor experiences such as breastfeeding compared with bottle-feeding facilitate dietary variety and vegetable acceptance [11,76]. In their statistical analysis, the authors described their initial model as including demographic information, and the final model included the variables that were significant in initial analysis, suggesting that confounders were considered, and these associations remained despite this adjustment. Feeding difficulties were also observed in infants who were introduced to lumpy solids at or after 10 mo of age, highlighting the importance of early introduction of solids between the ages of 6 and 9 mo [15]. Additionally, a more recent follow-up of the same cohort of children at age 7 y showed that children who had received their first complementary foods after 10 mo consumed fewer vegetables at 7 y than children who received solid foods between 6–9 mo [116].

Moreover, the texture of food has been shown to be an important determinant of food intake and satiation [117,118]. Considering that during chewing afferent stimuli reach the central nervous system and regulate food intake, harder foods that require more chewing cycles may have a positive influence on satiety and metabolism [119]. However, soft foods and beverages are usually consumed faster and, as a result, may be associated with overeating [14]. This is particularly important in children when dietary habits are still being established, and the pattern of food consumption can be perpetuated in adult life [2]. There is emerging research on the influence of food texture on energy metabolism in animal studies. Bae et al. [120] demonstrated that rats fed a 14-wk soft pellet diet showed glucose intolerance, insulin resistance, and hyperplasia of pancreatic β cells, even though no differences in energy intake or body weight was found between rats fed control pellets and those fed soft pellets. Supporting these results, Nojima et al. [121] showed that the hardness of food is an important determinant of the development of type 2 diabetes in a mouse model. Recent data showed that calorie intake, lipogenesis, and fat accumulation is higher in rats fed soft pellets *ad libitum* for 27 wk. Interestingly, the authors observed that energy expenditure, evaluated by oxygen consumption and locomotor activity, was higher in rats fed soft pellets than in control rats, which may explain the similarities in body weight between the 2 groups [122]. However, to our knowledge, no longitudinal clinical study analyzing dietary texture and general health conditions in childhood has been conducted.

It seems that there is a mutual relationship between the development of orofacial structures, exposure to food textures, and acceptance of foods with different textures in infancy. Also,

the reviewed studies suggest that it might be easier to get infants to accept new textures if they are introduced earlier within accepted time frames for introduction. Finally, animal studies showed that frequent consumption of soft food may contribute to the development of lifestyle-related diseases.

Discussion and Conclusions

In the present review, we have gathered insights into how early life experiences form the basis for the continuing development of food preferences during infancy and early childhood. Researchers show that such exposure may have persistent effects on feeding preferences and may influence healthy dietary intake. Consequently, clinical awareness about fetal programming effects, as well as a better understanding of putative mechanisms and mediators, can have an important impact on preventive medicine in this vulnerable population. Also, during the prenatal period, the sensory environment in which the fetus lives changes as a function of the food choices and nutrition of the pregnant person, as dietary flavors are transmitted through the amniotic fluid. The repeated exposure to these stimuli influences neonates' later behavioral responses to those same stimuli.

Following birth, flavors in human milk and/or formula are the primary postnatal influence on infants' developing food preferences. Compared to formula-fed infants who are exposed to limited sensory experiences due to the formula's consistent flavor, breastfed infants are exposed to a variety of constantly changing chemosensory experiences because human milk contains flavors from foods that are part of the diet of the lactating person. Many studies supported the idea that breastfeeding is associated with greater acceptance of novel foods at the beginning of complementary feeding and healthier growth trajectories during childhood.

The timing of solid food introduction is an unsettled debate. The WHO guideline is to exclusively breastfeed infants until 6 mo of age and introduce nutritionally adequate and safe complementary (solid) foods at 6 mo of age [111]. Later introduction of solid food is associated with feeding difficulties and a more restricted diet later in life [15,116], while early introduction has been shown to increase the risk of having obesity during childhood [112].

Another important component of food acceptance during complementary food is the exposure to foods of different consistencies. However, little attention has been given to this food sensory characteristic. Infants' eating behaviors toward foods with important contrasts of texture (like pieces in a purée) has not been established. Also, the effect of food texture on satiety and metabolism in children, as well as consequences on overall health, deserves attention in future studies.

Moreover, despite the importance of breastfeeding and food texture for the proper development of children's masticatory apparatus [16,113,115], their influence on food acceptance in early life has not been tested widely. In adolescents, individuals with overweight showed more changes in orofacial myofunctional aspects than normal-weight ones, and females reported peeling and cutting fruit (apples) in small pieces to better chew them [123]. In the elderly population, many studies have suggested that weaknesses of the masticatory muscles and decreased chewing efficiency due dental problems can have a negative impact on food intake, resulting in avoidance of foods that are

difficult to chew, such as meat, fruits, and vegetables [124–126]. Future studies are needed to clarify early factors in orofacial development that may impact the acceptance of foods with different textures.

Although this review is limited by its narrative nature, it is evident from the literature that long before the beginning of complementary feeding, there is the potential to introduce infants to a wide variety of flavors. Improving access to health care during pregnancy may help limit the effect of chronic diseases (e.g., hypertension, infections, malnutrition, etc.) that are associated with poor fetal growth and have a cascade beneficial effect on the offspring's health, development, and behavior, including eating habits. Human milk should be favored over formula, and in the rare events in which human milk is not indicated, families should be thoroughly informed about healthier feeding practices. Research is needed for a better understanding about the impact of different formula textures and flavors that favor healthy growth in childhood, while stimulating nutritious and varied eating habits. Infant growth must be carefully monitored, both as a prevention of stunting as per the original intent of the growth chart, but also for tracking rapid and excessive growth. Irregular mastication or chewing difficulties must be identified and treated to avoid potential long-term detrimental effects. Providing support and counseling about stimulating healthy food choices to families raising young children is inevitably beneficial to everyone, but may be more so to individuals during sensitive periods of their lives (e.g., pregnancy, lactation, infancy, adolescence).

Author contributions

The authors' responsibilities were as follows – KGOS, PMC, PPS: designed the study, performed literature search, selected articles to be included, and wrote the manuscript; JPMH, AKP: critically reviewed the manuscript and wrote the manuscript; JPMH: finalized the manuscript; and all authors: read and approved the final manuscript.

Conflict of interest

The authors report no conflicts of interest.

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