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Critical Reviews in Food Science and Nutrition

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https://doi.org/10.1080/10408398.2023.2214227

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https://doi.org/10.1080/10408398.2023.2214227

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REVIEW ARTICLE

Food oral processing and eating behavior from infancy to childhood: evidence on the role of food texture in the development of healthy eating behavior

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ABSTRACT
Eating behaviors develop in early life and refine during childhood, shaping long-term food choice and dietary habits, which underpin optimum growth and health. The development of Food Oral Processing (FOP) is of major importance in the establishment of eating behaviors at two scale levels: for the initial acceptance of food texture and for the longer-term development of eating behaviors associated to food intake. To date, both processes have been studied as independent topics and the current review proposes a parallel vision on their development from the onset of complementary feeding to later childhood. Individual factors affecting these FOP-related behaviors as they relate to food texture acceptance are discussed, alongside examples of interventions aiming at modifying them. Opportunity to better consider food textures when designing foods for children is addressed. Altogether, the review demonstrates the critical role of food texture in the development of a child's FOP skills, eating habits, and dietary patterns. These scientific knowledges need to be considered for the development of healthier eating behavior. We identify research gaps that need to be addressed and highlight the need to design foods that can support the development of healthy oral processing and eating behaviors among infants and children.

KEYWORDS
Children; developmental age; eating rate; energy intake; food oral processing; texture acceptance

Introduction

Eating behaviors develop in early life and are further refined during childhood, shaping long-term food choice and dietary habits. The eating patterns acquired during early childhood play an important role in shaping food acceptance and the dietary patterns that underpin optimum growth and health. During infancy and early childhood, children have higher nutrient and energy requirements relative to their size, due to the energy cost of growth and development. Despite this, in 2020 39 million children under the age of five were overweight or obese (World Health Organization (WHO) 2020) and childhood obesity remains a major preventable diet-related chronic condition. A challenge remains to encourage children to accept healthy foods and reduce their intake of energy-dense foods, with many focusing on the promotion and intake of nutrient-rich low energy foods such as vegetables, which are often poorly liked and under-consumed among young children in most European countries (Russell and Worsley 2013; Schwartz et al. 2018; Yngve et al. 2005). Matching energy requirements for growth with appropriate dietary intakes during this period is important to avoid rapid or delayed weight gain, with rapid weight gain during early childhood associated with an increased risk of obesity and metabolic syndrome in later life.

The factors involved in the development of infant and child eating behaviors and diets are multifactorial. The current narrative review focuses on the development of eating behavior and dietary patterns from a Food Oral Processing (FOP) perspective from early infancy, when eating behaviors start to develop, through to later childhood. We begin by describing early life development of oral anatomy and how children learn to eat and chew foods, and through this, accept different textures. These early life patterns stabilize to inform child eating behavior and we summarize how these behaviors impact child energy intake and growth. We outline the main factors involved in inter-individual differences in child eating behaviors and describe interventions that aim to foster food texture acceptance and slower eating rates. Finally, we discuss the need to consider the food textures that can support the healthy development of infant and child oral processing and eating behavior.

Etiology of FOP and associated anatomical development: prenatal to late childhood

Infants sucking and swallowing functions start to develop even before birth, during the embryonic and fetal periods, in line with the development of the oro-pharyngo-esophageal

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anatomy and the cerebral and brainstem pathways involved in their function (Barlow 2009; Delaney and Arvedson 2008). Sucking and swallowing of amniotic fluid is observed in most fetuses by 15 weeks of gestation (Delaney and Arvedson 2008), and continues throughout the second and third trimester. After birth and during the first few months of life, infants are fed a liquid diet in the supine position by sucking milk (from breast or from bottle). A new born-infants' mouth is narrow, with the volume of the oral cavity mostly filled by the tongue, and fat deposits in the cheeks. The jaw and cheeks stabilize the backward-forward movements of the tongue during nutritive sucking to ensure tongue movements are restricted thereby reducing the risk of choking (Meyer 2008). In addition, a smaller oral cavity with enlarged cheeks makes for more efficient feeding, as the infant can latch and form a vacuum for enhanced suction and improved breastmilk flow. During these early stages of feeding, the infant develops their ability to coordinate both swallowing and breathing functions simultaneously to avoid aspiration. A longitudinal study of infant feeding suggests that the coordination of breathing/swallowing matures during the first year of life, with two major shifts: the first after 1-week and the second between 6 and 12 months (Kelly et al. 2007).

The second half of the first year is a period of major development of oral processing skills where the infant transitions from dependent feeding in the supine position, to an upright independent feeding, and from liquid to semi-solid/solid foods (Nicklaus, Demonteil, and Tournier 2015). This diet transition usually starts between 4 to 6 months, though this varies widely (Campoy et al. 2018). Complementary feeding (CF) begins when the child can sit or stand independently in an upright sitting position, and is capable of balancing and controlling head movements (Delaney and Arvedson 2008). As the infant becomes a toddler their feeding skills undergo important developments through their experience and exposure to different food textures that require more diverse oral processing behaviors. This stimulates further anatomical, physiological and functional development of mastication (Nicklaus, Demonteil, and Tournier 2015; Le Reverend, Edelson, and Loret 2014). With increased control and dexterity of tongue movements, the risk of choking subsides, and over time the fatty tissues (sucking fat pads) in the cheeks decrease, leading to an increase in oral volume and more space for tongue movement and tooth eruption. Chewing stimulates the lengthening of the palate, and development of muscles and bone to support an enlarged oral cavity, alongside the lowering and elongation of the larynx and pharynx (Kelly et al. 2017; Remy et al. 2019; Vorperian et al. 2005; Stevenson and Allaire 1991; Ranly 1998; Hutchinson, L'Abbé, and Oettlé 2012). The oral and pharyngeal structures develop throughout early childhood, with accelerated development during the period between birth and 18-months (Vorperian et al. 2005). As the head and neck grow, the oral cavity volume increases, creating more space for the tongue to develop vertical and lateral movements. Tongue motion also becomes independent of those of the jaw and lips, allowing the child to move food from the center to the side of the oral cavity, promoting more efficient mastication.

The increased oral volume is also necessary for the eruption and alignment of infant dentition, and is supported by the elongation in the upper (maxilla) and lower (mandible) jaw bones and extension of the palate. These bones act as the anchor point for deciduous teeth which slowly begin to erupt concurrently with elongation of the jaw bone. Both palate elongation and tooth eruption are stimulated by chewing, highlighting the important reciprocal role of texture introduction in promoting wider food acceptance, balanced nutrition, and better anatomical development in the developing infant. Infants have a total of 20 primary teeth that emerge in distinct phases beginning with central incisors (6–12 months), lateral incisors (8–14 months), molars (13–19 months), canines (16–20 months), and second molars (23–33 months) arriving in sequence by 3 years of age. The eruption of the first molars creates stability in jaw position, offering a pivot that connects the maxilla and mandible bones, and fixes the occlusal contact within the jaw. Another component of oral development is the elongation, strengthening, and coordination of the muscles required to elevate (masseters and temporalis muscles) and depress (digastric muscle) the jaw during biting and chewing (Green et al. 1997). The apparent simplicity of chewing and swallowing belies an enormous complexity, with coordination among at least 26 pairs of muscles and 5 cranial nerve systems (Barlow 2009; Wilson and Green 2009). Jaw muscles activity (measured using electromyography) and jaw movements (3D-Kinematic) measurements performed in infants and toddlers show that the basic coordination of chewing and swallowing is in place but immature, with maturation of function only occurring between 9 and 36 months and characterized by better chewing motor control and temporal muscle coordination (Green et al. 1997; Wilson and Green 2009; Simione et al. 2018). The lips also play also an important role in the development of the chewing function, with improved muscle control reducing oral incontinence and allowing the oral cavity to remain closed during oral processing and bolus swallowing. Lip pressure increases steadily from 5 months to 3 years, and continues to increase more slowly between 3 and 5 years (Chigira et al. 1994).

The development of lips, tongue, and jaw movements together with teeth eruption provide the neural and anatomical support for the development of more complex and efficient chewing behavior as the infant grows. At the beginning of CF (4–6 months), most semi-solid foods are processed *via* sucking motions (Figure 1). A longitudinal evaluation of infant feeding reported a transition from sucking to chewing (up and down movements of jaw) motions, with chewing behavior being well established from 10 months (Demonteil et al. 2019). Alongside the anatomical development of chewing behavior is a rising capacity to break-down and process a wider range of more complex food textures using more varied oral processing strategies, that continue developing up to 18 months (Tournier et al. 2019). Chewing development can be characterized into two broad phases: the premolar (9-, 12-, and 18-months) and

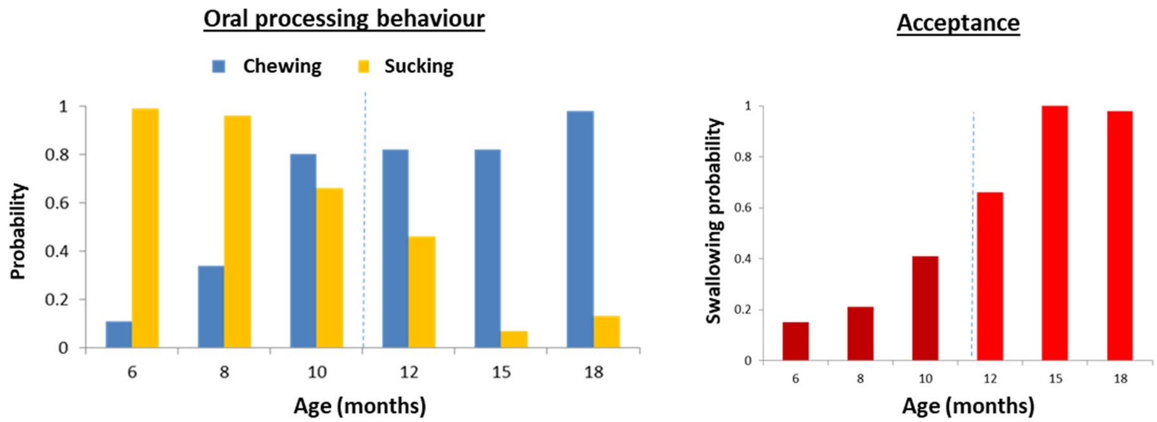

Figure 1. Longitudinal development of Food Oral Processing behavior and acceptance of a baby biscuit between 6 to 10 months and 12 to 18 months (Adapted from data published in Demonteil et al. (2019): Estimated probability of chewing, sucking, and swallowing. Sucking was defined as a backward-forward jaw movements, with intermittent lip closure and tongue-thrust reflex; chewing as up-and-down movements of the jaw with permanent lips closure).

molar (24- and 36- months) phases, with the latter being characterized by a better control of jaw movements and enhanced capacity to process harder food textures (Simione et al. 2018). Maturation of oral anatomy and chewing function results in a steady increase in chewing efficiency when consuming solid foods. The number of chews per bite and chew duration necessary to form a bolus for a standard food decreases from 6 months to 2 years, with the most marked changes occurring between 6 and 10 months (Gisel 1991).

The full development of mature chewing can take several years and chewing movement continues to be refined during the preschool period, with a decrease in number of chewing movement's and duration between the age of 2 and 5 years (Gisel 1988; Schwartz, Niman, and Gisel 1984). A systematic review showed the continuous improvement of masticatory function in line with dental eruption and the development of the oro-facial structures, with most significant development of chewing parameters occurring between 6 and 12 years of age (Almotairy et al. 2018). The transition to "adult-type" masticatory behavior occurs between 10 and 14 years where the development of chewing efficiency during later childhood and early adolescence is further influenced by the transition from deciduous ("milk-teeth") to permanent dentition (Almotairy et al. 2018). Previous research describing the developmental profile of chewing cycles from preschool to school-age children (2 to 8 years) highlights the important role of food texture in oral processing, and demonstrates the eating skills needed to consume different food textures mature at different rates (Gisel 1988). The next section describes the inter-relationship between the development of oral processing skills and the broadening of the food textures accepted and consumed throughout early childhood.

Development of FOP skills and texture acceptance

Texture acceptance during CF period

The early development of oral processing skills occurs in parallel with the developing infants' acceptance of a wider complexity of semi-solid and solid food textures. CF is a period of gradual introduction of foods other than milk to the infant diet, which is necessary to meet the nutrient and energy requirements of the growing infant (Schwartz et al. 2011). CF corresponds to the transition between a purely liquid diet to the consumption of semi-liquid, semi-solid, and solid foods. At first, complementary foods are usually offered as purees of blended foods served on a spoon, and over the subsequent months, the texture evolves to more solid and chewable foods, ultimately supporting the infant to develop the oral skills to consume the same foods as the rest of the family. The transition of the infants' diet toward family table foods is determined by the frequency of their exposure to more complex textures and the rate and extent of the development of their oral skills. During the early phase of CF there is a mutual benefit in the emergence of oral skills and texture acceptance, as one influences the other in a complementary cycle. As oral processing skills continue to improve the young child can consume more diverse textures which encourages the introduction and acceptance of more complex and challenging textures that further stimulate the development of oral processing skills.

The transition from sucking to chewing behavior and the protracted development of masticatory function that takes place during CF develops in parallel with food texture acceptance as the infant (<12 months) becomes a toddler (12–14 months). For example, infants from 6 to 12 months that are offered applesauce with different textures (puréed, lumpy, diced) displayed more negative expressions, negative head and body movements when presented with more complex textures; whereas toddlers (13–22 months) showed more positive head and body movements, and more eagerness for complex textures (Lundy et al. 1998). At a given age, children are more likely to refuse foods they are not able to process orally and prefer textures that they can more easily consumed, over those that are more challenging. Previous research has shown for example that at 12 months of age ad libitum intake of carrot was significantly higher when offered as puree rather than chopped form (Blossfeld et al. 2007).

Food texture acceptance develops over time and concurrently with oral development, yet to date only one study has longitudinally profiled changes in texture acceptance within the same group of infants at two time points, between 6 and 10 and between 12 and 18 months (Demonteil et al. 2019). Acceptance was defined as the proportion of children swallowing test foods at each time-point. At 6 months, granular purees with or without small soft pieces were largely accepted (>75% of children) and consumed *via* sucking (Demonteil et al. 2019). The further development of chewing behavior between 6 and 10 months coincided with shifts to accept more challenging textures, that rely on a wider range of oral manipulations and processing skills. For example, acceptance progressed from softer pureed foods to those with sticky pieces and harder breads (Demonteil et al. 2019). Between 12 and 18 months, children chewed the food and during this period began to accept harder pieces of raw vegetables and pasta (i.e., penne) such that these foods were accepted by at least 50% of children by 15 months, though some children still could not eat them at 18 months (Demonteil et al. 2019). Food texture acceptance continues to develop throughout early childhood with one survey study on 4–6 to 30–36 months children reporting an increase in the child's ability to eat hard and large pieces of solid food as well as bi-phasic textures composed of pieces in a thin liquid phase, offered by their parents over the entire period (Tournier, Demonteil, et al. 2021).

Texture acceptance development in preschool and school age children

Food texture plays a more important role in food rejection among young children than in adults (Szczesniak 1972; Werthmann et al. 2015; Chow et al. 2022). Food texture acceptance develops in parallel with the ongoing development of oral anatomy and function, and this progresses from the eruption of the first milk teeth in the preschool years to the emergence of the first permanent maxillary premolars at 10 years (Szczesniak 1972). This represents a dynamic stage of child oral development as teeth emerge and are lost at different stages during this rapid period of change, with a resultant impact on the number and position of occlusal contacts. Children's texture preferences evolve over the same time period, with initial division into hard- versus soft-likers (Laureati et al. 2020), and subsequently more diversity in texture preferences as children gain more experience with food texture over time. Hardness is likely not the only textural parameter that influences children's texture acceptance. Low fatty-mouthfeel and low cohesiveness are specific texture attributes of vegetables that have also been linked to their lower acceptance and consumption compared to other food groups among Australian children (Poelman, Delahunty, and de Graaf 2017). Bi-phasic textures with pieces inside, or those presenting a dynamic texture contrast can also polarize preferences and are often less liked by children (Szczesniak 1972; Werthmann et al. 2015; Chow et al. 2022) as well as textures that are greasy, slippery, or slimy (Szczesniak 1972). In general, children develop preferences for textures that are 'easily' ingested as a function on their oral capacity, and which pose a low risk of choking. This evolves further as the child gains more experience across a wider set of food textures.

Importantly, these textural preferences have an important impact on the diet a child accepts and habitually consumes, and through this can influence the developing child's usual dietary patterns, and the diversity of nutrient and energy densities they encounter in their habitual diet.

Development of children's eating behaviors during meal-times and links to growth

The parallel development of oral anatomy, masticatory function and texture acceptance has implications for broadening the complexity of the dietary environment, but also supports the development of stable eating patterns that associate with meal size and habitual energy intakes. Eating behaviors begin to stabilize in early childhood and drive energy intakes, growth and body composition during early childhood. Adults that eat faster consume more energy from ad libitum test meals (Robinson et al. 2014), and research in children shows similar patterns, with differences in eating rate observed in early life associated with differences in growth rate, fat mass, and body composition in later childhood (Teo and Forde 2019).

Early research among infants (2- to 4-week old) has shown that those observed to have a greater sucking voracity, later had a faster eating rate and more rapid prospective weight gain over time (Agras et al. 1987, 1990). Among preschool children, eating rate has also been shown to be predictive of weight gain over time. For example, Berkowitz et al. observed that children with a higher eating rate (mouthfuls/min) at 4 years of age had more rapid weight gain by 6 years of age (Berkowitz et al. 2010). These findings were confirmed among children in a Singaporean birth cohort (Forde, Fogel, and McCrickerd 2019) that showed a rapid eating style was a stable behavioral marker for obesity risk and raid weight gain, predicting changes in BMI_z and adiposity between 4.5 and 6 years. Research on twins has shown a linear relationship between faster eating rates and higher weight gain, with an increase of 0.18 bites/min for each unit increase in body mass index among the children studied (Llewellyn et al. 2008). Differences in child eating behavior are stable over time and have been linked to differences in eating micro-structural patterns within a meal including eating rate (g/min), average bite size, and chews per bite (Fogel et al. 2017a). Observed differences in eating behavior have been associated with weight status (Forde, Fogel, and McCrickerd 2019). Across a wide range of population-based epidemiological surveys, eating at a faster rate has been associated with increased energy intakes, body weight, cardio-metabolic risk, risk of type-2 diabetes, and higher adiposity (Teo and Forde 2019; Teo et al. 2020). Recent findings from the Growing up in Singapore to Healthier Outcomes (GUSTO) birth cohort has shown a linear relationship between faster eating rates and energy intake within an ad libitum meal, with children that eat faster consuming up to 75% more energy within the same test-meal, compared to children that ate at a slower rate (Fogel et al. 2017b). Faster eating was also associated with higher child BMI_z scores, and increased adiposity at 4.5 and prospectively within the same children at 6 years. Child faster eating rate at 4.5 years was a significant predictor of their eating rate, energy intake, and prospective weight change at 6 years (Forde, Fogel, and McCrickerd 2019). In addition, children that eat faster had higher increases in both BMI_z and adiposity compared to children that ate slower (McCrickerd, Fogel, et al. 2017). These findings suggest that once a child's eating behavior stabilizes, it can have a sustained impact on energy intakes and contribute to increased body weight and adiposity throughout childhood. This eating style has been described as "obesogenic" and is characterized by larger average bite size (g), reduced chewing per bite and a shorter oro-sensory exposure time (Fogel et al. 2017b). A wide range of early life risk factors have been identified that predict later childhood propensity to develop obesity. These include factors such as gestational age of the child at birth, breast feeding duration and age of introduction of solid foods (Aris et al. 2018). Recent modeling has shown that whereas the cumulative risk of later obesity is linked to these early life factors, the strength of the relationship between "at risk" to sustained higher energy intakes and rapid weight gain is moderated by the presence of eating behaviors, such as selecting larger portion size, eating at a faster rate and eating in the absence of hunger. Only when "at risk" children exhibit these behaviors do they transition to the overweight or obese weight category (Fogel et al. 2020). Results highlight the importance of early life eating behaviors in moderating the transition from risk to obesity, and highlight opportunities to intervene during the early-life development of these eating behaviors when trying to reduce obesity risk.

Early life dietary experience influences the development of FOP behaviors, yet today the exact process remains unclear. Early-life breastfeeding exposure has been proposed as an important link to the development of feeding skills in early childhood, yet there is little evidence to support the association between breast-feeding and the development of childhood eating behaviors, including eating rate (Pang et al. 2020). Others have suggested the "drive to eat" is motivated by energy requirements and lean-muscle mass in young infants (Wells et al. 2021), with preliminary findings in adults showing associations between faster eating rates and higher fat-free mass and higher basal metabolic rates (Henry et al. 2018). These preliminary findings require further research to better understand the metabolic and physiological drivers of stable faster eating rates. Indeed, a wide range of early life influences are likely to converge on the emergence of eating behaviors during childhood, and in the next section, we provide an overview of the environmental, parental, and food properties that most influence the development of children's eating behaviors.

Individual factors that influence the development of texture acceptance and eating behaviors

During infancy and early childhood, the rate of oral anatomy and oral processing skill development varies widely between children, and this can have a strong influence on child food texture acceptance and the development of oral processing skills. This variation is due to underlying genetic and developmental differences between children, but can also be strongly influenced by the timing and quality of complementary food introduction, and there is a reciprocal relationship between the development of oral anatomy and feeding skills, and a child's early life exposure to different textures in their diet exposure. Here we summarize the important aspects that inform a child's food texture acceptance and eating behavior during a meal; including complementary food texture (timing and quality), parental feeding practices, oral development and appetitive traits, and oral-tactile sensitivity.

Influence of early life experiences with food texture

Familiarity and experience with food textures plays a significant role in the development of feeding skills and food texture acceptance, as exposing young children to a wide variety of food textures promotes experiential learning and encourages the child to adapt their chewing behavior and muscle activity to a more diverse set of texture challenges. Research has shown that the both the timing and the variety of food texture introduction are important (Nicklaus 2011). A sensitive period or even a critical period for textures introduction has been mentioned (Harris and Mason 2017; Nicklaus and Schwartz 2019). For example, introducing lumpy foods after 9 months of age was shown to be associated with a greater prevalence of feeding difficulties, food fussiness, and lower consumption of family foods by age 15 months, compared to children who received these textures earlier (Northstone et al. 2001; Nicklaus 2016). By age 7 years, children introduced to lumpy foods at a later stage consumed fewer key foods groups from a nutritional perspective such as fruit and vegetables (Coulthard, Harris, and Emmett 2009). In addition to the timing, the type and variety of food textures introduced also plays an important role (Tournier, Bernad, et al. 2021). The strongest predictor of intake and liking of chopped carrots at 12-months was the familiarity with different textures, especially chopped foods (Blossfeld et al. 2007). Among 15-month old children, acceptance of eight textured foods assessed in a laboratory was associated with exposure to a higher variety of food pieces, but not linked to their earlier exposure to pureed foods (Tournier, Bernad, et al. 2021). This suggests that children should be given the opportunity to experience a wide variety of food textures at a developmentally appropriate age to facilitate later texture acceptance and broaden their dietary variety. There is also an important and often overlooked link between consuming age-appropriate but challenging textures, and the development of oral anatomy and feeding skills. Encouraging children to process and consume more challenging textures helps to stimulate chewing activity which in turn improves muscle coordination, assists in increasing palate length, supports the eruption and alignment of dentition, and improves coordination of the neural and muscle control needed for the development of chewing behavior (Green et al. 1997; Wilson and Green 2009; Nicklaus, Demonteil, and Tournier 2015; Forde et al. 2021). Successful transition to more challenging texture is necessary for a wider dietary variety, but also serves to support the proper development of toddler chewing and swallowing skills and the progressive acceptance of increasingly complex textures. Conversely, children that have poor masticatory efficiency due to the sustained consumption of softer foods into later childhood, experience delays in their exposure to more challenging textures, and this, in turn, can negatively impact both healthy tooth eruption and alignment, and the development of feeding skills (Gavião, Raymundo and Rentes 2007; Maeda et al. 1989).

Parental feeding practices influence the development of child texture acceptance and eating behavior

In selecting and providing foods for their children, parents shape their child's early life exposure to food textures, and through this moderate the pace of experiential learning. In addition to providing foods, parents can also strongly influence their child's eating behavior and texture preference through their practices of new food textures introduction. A recent survey of parental feeding practices revealed that children that are regularly fed with commercial baby foods experience a lower variety of food textures, compared to those offered only home-made/or commercial foods that are not specifically formulated for infants (Demonteil et al. 2018). Parental feeding practices which encourage children to regularly consume foods with their fingers between 11 and 29 months have been associated with higher acceptance of foods with more complex textures (Tournier, Demonteil, et al. 2021). Parents can prompt, encourage, restrict, or assert certain feeding behaviors during meals times, and this can have a considerable impact on the emerging eating behaviors and textures a child learns to accept (Faith et al. 2004, Fries et al. 2019). During the preschool years, mealtime parental feeding practices exert a significant influence on a child's experience with food, and their subsequent eating behaviors. Modeling of healthy food acceptance and intake has been shown to promote healthier intake patterns among children, whereas food restrictions and pressure to eat has been associated with higher BMI_z scores (Quah et al. 2018). Research has shown that children that were frequently prompted, encouraged or restricted during meal times (i.e., experienced more parental feeding practices) eat at a faster rate and consumed significantly more energy, than children who experienced less frequent parental feeding practices (Fogel et al. 2019). The use of feeding practices tended to be more frequent among girls than boys, although in both cases children that experience the most feeding practices consistently eat at a faster rate and consume more energy (Fogel et al. 2019). Faster eating rates have been shown to mediate the relationship between appetitive traits linked with higher energy intakes, such that children with appetitive traits associated with greater energy intakes typically only consume more energy when they also eat at a faster rate (Fogel et al. 2018).

A child's eating behavior can be influenced by parental feeding practices, but parents also adapt their feeding practices in response to the eating behavior they observe in their children, such that there is a bi-directional relationship between child eating behavior and the parental feeding practices used at mealtimes (Quah et al. 2019). Feeding practices related to the use of restrictions and slowing prompts to encourage children to eat at a slower rate were adopted by parents in response to children who eat faster and consume larger portions (Fries et al. 2019). In doing so, parents may invertedly prompt and restrict and apply feeding practices that are associated with faster eating rates and greater intake, thus further promoting these eating behaviors. Taken together, these findings highlight the importance of early life experiences with food texture and the associated parental feeding practices a child experiences during this rapid period of development during which their eating behaviors begin to stabilize. Once established, these eating behavior are difficult to change, and are likely to contribute to habitual energy intakes and growth outcomes over time.

Influence of Individual differences in oral physiology

As mentioned tooth eruption and the development of oral processing skills continues throughout the first 24 month of life and progress rapidly following the introduction of complementary foods (Nicklaus, Demonteil, and Tournier 2015; Simione et al. 2018). Progressive increases in masticatory function are typically matched by similar increases in the complexity and challenges posed by the food textures consumed. The number of teeth a child has was associated with higher intakes of chopped carrots at 12 months old (Blossfeld et al. 2007) but the same relationship was not seen for intake of dried bananas and crackers at 12–18 months old (Remijn et al. 2019) nor for swallowing ability for eight textured foods at 15 months (Tournier, Bernad, et al. 2021). This highlights a gap between the development of oral physiology with chronological age, and the experiential oral processing skills that are learned through experience and better reflect a child's developmental stage. Associations have been seen between maternal reports of their child's acceptance for products varying in texture and the number of teeth of the infant, which may explain why when children have more teeth their parents begin to introduce newer and more diverse textures, thus widening the opportunity for improved experiential learning (Tournier, Bernad, et al. 2021). The number of teeth is often considered by mothers as a signal of developmental maturity and may act as a cue to parents to introduce more textured foods, despite the fact that number of teeth is not an objective marker of oral processing skills or ability to handle more complex textures (Demonteil et al. 2018).

During the preschool period children rely on healthy dentition for the normal mastication that supports acceptance of a wide range of foods. A child's dentition remains stable throughout the preschool period until they are progressively replaced by permanent adult dentition beginning from age 6 to 7 years and lasting until age 10 to 12 years. Chewing difficulties can impact food texture acceptance and rate of eating, and associations have been seen between maternal reports of their child's chewing difficulties and eating rate observed when consuming raw apple segments (Schwartz et al. 2021). Children with chewing difficulties orally process foods for longer, with a smaller bite sizes, than children that have no or limited chewing difficulties (Schwartz et al. 2021). Poor oral hygiene and health practices during this period can lead to loss or damage to teeth, causing oral pain and discomfort which can significantly impede oral processing, food intake and impact nutritional status (Clarke et al. 2006; Forde et al. 2021). Early Childhood Caries (ECC) is defined as the presence of more than one decayed, missing, or filled teeth among children under the age of 6 (AAPD 2008) and is recognized as a global pandemic (Schwendicke et al. 2015; Tinanoff and Reisine 2009) that adversely affects a child's quality of life through altered sleep patterns, social and emotional disturbances, and nutritional difficulties. Children with untreated ECC have impaired masticatory efficiency and produce less broken-down boluses compared to age-matched children with good oral health (Linas et al. 2020). Children with ECC develop alternative behavioral strategies to overcome feeding difficulties and discomfort due to their impaired masticatory performance and often exclude harder foods from their diet to avoid chewing in areas with painful carious teeth (Linas et al. 2019). Children with fewer occlusal contacts and a weaker bite force rely more on soft and smooth foods and tend to avoid more challenging food textures such as fruits, vegetables, and many protein sources (Araujo et al. 2016; Yamanaka et al. 2009). Changes in dentition and oral processing capabilities occur at a critical time when children are learning to chew and this can lead to sustained changes to oral processing abilities and food acceptance that can impact dietary intake patterns. Prolonged exposure to poor oral health can lead to sustained dietary changes, weight loss, and sub-optimal growth when compared to children with normal dentition (Acs et al. 1999; Ngoenwiwatkul and Leela-Adisorn 2009; Sachdev, Bansal, and Chopra 2016; Versloot, Veerkamp, and Hoogstraten 2005). The treatment for extensive ECC is comprehensive dental treatment and includes multiple extractions or even in some cases complete removal of the child's primary teeth, where children are left with few or no occlusal contacts for mastication and bolus preparation. Recent research has compared the impact of dental treatment on chewing efficiency and food preferences among ECC children and shown that despite the reduced occlusal contacts, chewing efficiency remained similar pre- and post-dental treatment and children adapt their eating behavior and increase the number of chews needed to masticate harder foods. Importantly, children reported no change in mastication function or mixing ability score for other foods or changes in food preferences following extensive dental treatment (Khong et al. 2022).

Influence of Individual differences in tactile sensitivity, eating style and appetitive traits on child eating behavior

Variability in children's acceptance of different food textures can be a result of physiological or experiential differences, but may also reflect an underlying behavioral manifestation of their oral sensitivity, interest, and enjoyment of food and their motivation or "drive" to eat. Sensitivity to tactile sensation plays an important role in the acceptance of foods and this is especially linked to texture refusals (Coulthard, Harris, and Fogel 2016; Harris and Mason 2017; Nederkoorn, Jansen, and Havermans 2015; Ross et al. 2022). Children described as "tactile defensive" have a fair to poor appetite, hesitate to eat unfamiliar foods, and often have problems eating challenging food textures such as vegetables (Smith et al. 2005). Higher tactile sensitivity is common among children with Autism spectrum disorder, and can significantly limit food acceptance and results in atypical eating patterns (Bandini et al. 2010; Cermak, Curtin, and Bandini 2010). Similar tactile and sensory sensitivity has also been observed among children with Downs syndrome (Bruni et al. 2010). Different methods have been proposed to objectively quantify the perception of oral tactile stimuli by children (Chow et al. 2022). So far, the link between tactile perception and texture aversion has not been established (Chow et al. 2022).

Children differ in their drive to eat, enjoyment of food and sensitivity to feelings of hunger and fullness (Carnell and Wardle 2007). These have been termed "appetitive traits" and can be measured using tools such as the Children Eating Behavior questionnaire (CEBQ; Wardle et al. 2001) which describe a child's appetitive behaviors and eating styles across eight different dimensions. Experimental studies showed that toddlers (12–18 months) who scored high in "food enjoyment" and "food responsiveness" and low for "food fussiness" tend to have a higher acceptance for more challenging food textures foods (Tournier, Bernad, et al. 2021) and higher intake of freeze-dried bananas and crackers (Remijn et al. 2019) and chopped carrots (Blossfeld et al. 2007). Associations have also been observed among preschool children appetitive traits and their eating behaviors. Children that were higher in "food responsiveness" and "enjoyment of food" were consistently associated with faster eating rates (Fogel et al. 2018). A faster eating rate was also associated with poorer "satiety responsiveness" (Fogel et al. 2018) suggesting that children that eat faster and consume more ad libitum, may also be less sensitive to the onset of satiation and have a reduced ability to regulate food intake.

An on-line study of 6–13 years old children's food texture preferences has shown an association with different levels of sensory sensitivity and food neophobia. Here it was found that children who preferred softer and non-particulate versions of foods were also more neophobic and higher in sensory sensitivity than those children that accepted a wider range of textures (Cappellotto and Olsen 2021). Separately, in another study children were classified by their questionnaire responses as being "texture sensitive" (TS) or "non-texture sensitive" (NTS), where TS children were more likely to reject specific food textures between 4 and 36-months and were fussier between ages 5–12 years, compared to NTS children (Ross et al. 2022). Identifying children who are TS can enable parents to adapt the introduction of complementary food textures and better match the child's developmental stage with the experiential learning that is necessary to develop the oral processing skills needed to accept a diverse range of foods for a balanced diet. This makes it possible to adapt both a food's texture properties and the appropriate parental feeding practices to this critical phase in the child's development of their oral processing capabilities.

Interventions targeting infant and children oral processing, texture acceptance and eating rate

Texture exposure can influence acceptance and subsequent eating behavior and can be an important target for interventions to support the development of healthy eating habits and dietary patterns. A limited number of studies to date have focused interventions on targeting food texture exposure to enhance texture acceptance, or slower eating rate to better regulate energy intake in children. Here we provide a short summary of some of the trials conducted to date.

Promoting texture acceptance during infancy and early childhood

Infancy is a critical period for the introduction of textures and the development of oral motor function (Harris and Mason 2017). Children should be encouraged to consume lumpy foods between 8 and 10 months at the latest, and as recommended by the ESPGHAN prolonged use of pureed foods should be discouraged as it may lead to developmental delays in later childhood (Fewtrell et al. 2017). The most effective approach to promote enhanced texture acceptance is through improved exposure to food textures, both through food textures presented and the parental feedings practices used to support their acceptance. Among 8-months-old infants, a 4-week pilot intervention showed that increasing the textural properties (number, size and hardness of pieces) of commercial baby foods offered at meals positively impacted the infants chewing capability for carrot and potato pieces, but not for banana piece or mashed foods (da Costa et al. 2017). In France, food texture was poorly considered in national guidelines on CF before very recently, a pilot intervention evaluated the effect of newly developed guidelines that promote the introduction of textured foods between 8 and 15 months on children's later experience and acceptance of food textures (Tournier, Bernad, et al. 2021). As compared to usual care (national guidelines), providing guidance alongside monthly counseling by a dietician significantly increased the introduction of small and soft food pieces. However, this guidance alone was not sufficient to effectively influence the introduction of more challenging food textures (Tournier, Bernad, et al. 2021). An earlier randomized control trial examined the impact of baby-led weaning practices on children's eating behavior at the age of 12 months to compare infants that were introduced to CF using either traditional spoon-feeding of purees versus self-feeding of whole foods (the Baby-Led Introduction to Solids, BLISS RCT; Taylor et al. 2017). Results showed similar child growth using both methods, and less reported "food fussiness" for children fed with the baby-led approach. However, this trial did not examine whether children varied in their oral processing skills or food texture acceptance. Another study that targeted food texture refusal among preschool and school-age children reported that feeling a foods texture with hands can positively influence later acceptance of foods with the same texture (Nederkoorn et al. 2018). These studies highlight the potential of adapting the experiential learning approach, through texture exposure and feeding practices, to enhance later texture acceptance and intake.

Intervention targeting eating behavior

Recognizing children that display faster eating rates could be used to identify those most at risk for sustained higher energy intakes and later obesity and creates affords new opportunities to develop eating behavior strategies that mitigate the impact of faster eating on energy intake (Forde, Fogel, and McCrickerd 2019). Several interventions have yielded some success in reducing children's eating speed by prompting children to reduce eating rate during meals using devices. In one example, children were shown to reduce eating speed, energy intake, and subsequent BMI using a device that tracks meal eating speed against an eating rate target (Ford et al. 2009). In a separate intervention, children were instructed to take longer breaks between bites using a timer which slowed eating rate and reduced energy intake and BMI in among the children that adhered to the protocol over the intervention duration (Salazar Vázquez et al. 2016). A recent 8-week trial provided children with psycho-educational and behavioral techniques to slow their eating rate, with results showing a reduction in both eating speed and BMI, and an increase in food enjoyment among children that successfully completed the intervention (Faith et al. 2019). Whereas each trial has shown initial success, the long-term adherence and acceptance of these devices in reducing eating speed and supporting a better regulation of ad libitum energy intake remains to be seen, with several trials highlighting the difficulty in retaining participants for long-term compliance to the regime (i.e., Hamilton-Shield et al. 2014).

Another approach to slow eating rate could be to modify the textural properties of the foods provided to children, to promote small bite size, longer oral processing time and a slower eating rate and calorie intake within meals. We tend to adapt our oral processing behaviors to the food properties and textures we encounter during meals and snacks, and previous studies have demonstrated that texture modification can be applied to both increase oral processing duration and decrease eating rate and energy intakes during ad libitum test meals (Forde and de Graaf 2022). The data to date has been collected in adult populations (see Bolhuis and Forde 2020; Hogenkamp and Schiöth 2013; Robinson et al. 2014 for reviews), yet the opportunity to apply food texture modification to slow eating rate and reduce energy intake has yet to be tested with children. One study demonstrated that the geometric properties (shape and serving size) of vegetables (whole vs. diced carrots) can influence ad libitum intake in children, with almost 70% of children consumed more whole than diced carrot (Goh, Russell, and Liem 2017; Liem and Russell 2019). In another trial changing the form of an apple offered at the beginning of a mid-afternoon snack meal had no impact on the energy consumed of another food offered during this meal (Schwartz et al. 2021). Research in adult has shown that serving meals whole or mashed (Forde et al. 2013), or with harder/softer components (Bolhuis and Forde 2020), or as thicker/thinner textures (McCrickerd, Lim, et al. 2017) can reduce eating rate. Reducing eating rate by approximately 20% reduce energy intake by between 10% and 15% (Forde 2018). To date, similar trials on modifications of within meal food textures and the impact on eating rate have not yet been completed with children, so it remains unknown whether similar effects would be seen on energy intakes. However, it is likely possible to utilize changes to food texture to slow the rate of consumption and reduce intakes and through this mitigate the potential risk of overconsumption from softly textured foods that are nutrient poor and high in energy density. Food-based approaches to changing child eating behavior are appealing given the plasticity of food preferences and behaviors at this early age, and the opportunity to implement the intervention within family meals and for the changes to be effective at each eating occasion.

Designing foods for infants and children: the importance of considering food texture

Food for infants and toddlers: the need to define science-based age appropriateness

Offering products that are well adapted to a child's FOP skills during CF could facilitate greater acceptance of novel textures, while simultaneously stimulating the development of healthy eating behaviors. Ready-to-eat commercial complementary foods represent an important part of the child's early introduction to food texture (Caton et al. 2014; Mesch et al. 2014; Reidy et al. 2018; Schwartz et al. 2013; Schwartz et al. 2018). The dual challenge in developing such foods is the requirement to have sufficient texture to support optimal development of chewing skills while also ensuring foods can be safely ingested by the child. These commercial preparations are designed to meet nutritional needs at different stages of the child's development, however, little information is available on the textural consistency of many commercial complementary food products that target specific age-groups and developmental stages (Nicklaus, Demonteil, and Tournier 2015). Most products marketed as complementary foods for toddlers are positioned by age and recent research has highlighted the wide diversity of food textures within each age recommendation for the same product categories, and the disparity with parents' expectations for textures within each age category (Tan et al. 2022). This diversity makes it difficult for parents to ensure the consistent presentation of staged and appropriate texture challenges to support the development of oral processing skills during the introduction of complementary foods. Future research is needed to address the question of what are the optimal food textures to promote later texture acceptance and promote optimal oral development for complementary food products at different stages of the child's development.

Viscosity and sensory assessments of indigenous and commercial complementary porridges commonly used in South African communities show that some recipes for porridge-based complementary foods are not be appropriate for the weaning infant due to the thickness, stickiness. and difficult to swallow consistency. Often, parents resort to thinning the mixture with water which can significantly reduce the consistency of the porridge, but also the nutrient density and creating nutrient short-falls over time (Onofiok and Nnanyelugo 1998). Reducing the viscosity of these porridges while maintaining food acceptance and nutrient density remains a significant challenge (Thaoge et al. 2003). A characterization of jars and plates on the French market in 2014 intended for 8 to 24 months children, showed that they were mainly composed of food pieces embedded in a liquid/semi-liquid phase (Nicklaus, Demonteil, and Tournier 2015). Evaluation of the particle size properties of these weaning foods revealed large differences in particle size and hardness that were not related to the suggested age. The quantity and the size of the particles tended to increase with suggested age; however, important variations were observed across brands and recipes (Nicklaus, Demonteil, and Tournier 2015). The textural properties of pieces present in commercially infant meals and fruits could impact on the development of children chewing capability, as shown after a 4 week-exposure (da Costa et al. 2017). In the US, another study evaluated the suitability of first baby finger food is complying with the recommendations of the American Academy of Pediatrics of starting with finger foods that are: soft, easy to swallow, and cut into small pieces (Awadalla, Pham, and Milanaik 2017). They conclude that "products marketed with the same life-stage designation (crawler) varied considerably with regard to their compliance with AAP recommendations." Similar studies on UK and Asian complementary snacks and purees showed a wide diversity of claims and textures in products marketed to children within the same age categories, suggesting a wide diversity in food textures and a lack of consensus on the most appropriate textures being recommended to parents of children at similar ages and developmental stages (Tan et al. 2022; Garcia et al. 2022). A study of chewing motor coordination and control evolution between 9 and 36 months (Simione et al. 2018) used age-appropriate and commercially available cereals food products. Here the authors conclude that some solid textures are better adapted for immature mandibular control than others. These studies suggest that further research is needed to identify science-based guidance regarding the safety and age-appropriateness of commercial complementary baby foods textures and to align recommendations with consistency within and across commercial product categories that target specific developmental stages.

Considering FOP and eating rate in children's food textures

In line with the clear demonstration of the importance of expose to textures during the CF period, the growth of baby "food pouches" as a novel method for infant feeding merits consideration (Theurich 2018). They are "pureed, semiliquid foods for infants, and young children packed in squeezable plastic pouches usually equipped with a spout and screw cap" (Koletzko et al. 2018). Concerns have been raised about the lack of stimulation of feeding skills when children self-feed *via* sucking, and the lack of responsive interaction between the child and parents or other care givers (Koletzko et al. 2018, 2019). Responsive feeding is important in supporting the developing infant's ability to respond to hunger and satiety cues and adjust food intake accordingly (Taylor et al. 2021). As such, many questions have been raised concerning the potential impact of regular use of food pouches in the development of children's eating skills, behavior, and health. There remains an urgent need for research to better understand the impact of pouches on the development of independent feeding skills, oral processing behaviors and the longer-term impact this has on the child's ability to regulate intake in response to feelings of hunger and fullness (Taylor et al. 2021). Food texture can be an important lever to moderate oral processing behaviors and energy intake and future research should consider the application of texture to in helping to moderate the flow of energy and nutrients through the developing child's diet (Bolhuis and Forde 2020). Considering the textural properties of commercial food products marketed for school age children deserves further attention in the future.

Conclusion

This review proposed a paralleled vision on the development of food texture acceptance and of eating rate from early infant to late childhood, in the light of the development of children's oral processing skills. The origin of variability in texture acceptance and eating behavior share common individual factors and parental feeding practices. Modifying both children's FOP skills and eating behavior *via* food texture exposure remains an opportunity to support the development of healthy eating patterns in early life. However, so far interventional studies are still scarce and texture needs to be better consider by industrial product developers. From the child's perspective, how early life texture experiences can influence later development of FOP skills and modulate the development of both texture acceptance and eating rate remains an open question. Further multidisciplinary research is thus needed to better understand the complex interplay between food textural properties, the development of oral anatomy and food processing capabilities and the subsequent emergence of stable eating behaviors and dietary patterns linked to health outcomes from early infancy and into later childhood.

Disclosure statement

The authors report there are no competing interests to declare.

Funding

The author(s) reported there is no funding associated with the work featured in this article.

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