

# Innate and learned preferences for sweet taste during childhood

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## Purpose of review

In nature, carbohydrates are a source of energy often equated with sweetness, the detection of which is associated with powerful hedonic appeal. Intakes of processed carbohydrates in the form of added sugars and sugar-sweetened beverages have risen consistently among all age groups over the last two decades. In this review, we describe the biological underpinnings that drive the consumption of sweet-tasting foods among pediatric populations.

## Recent findings

Scientific literature suggests that children's liking for all that is sweet is not solely a product of modern-day technology and advertising but reflects their basic biology. In fact, heightened preference for sweet-tasting foods and beverages during childhood is universal and evident among infants and children around the world. The liking for sweet tastes during development may have ensured the acceptance of sweet-tasting foods, such as mother's milk and fruits. Moreover, recent research suggests that liking for sweets may be further promoted by the pain-reducing properties of sugars.

## Summary

An examination of the basic biology of sweet taste during childhood provides insight, as well as new perspectives, for how to modify children's preferences for and intakes of sweet foods to improve their diet quality.

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## Introduction

Carbohydrates are the primary source of energy for all body functions. In nature, carbohydrates are often equated with sweetness (e.g., fruits, honey), the detection of which is associated with powerful hedonic appeal. In recent years, the increasing use of both nutritive and non-nutritive sweeteners has resulted in a food supply that can also provide sweetness in processed (e.g., foods with 'added sugars') forms [1]. Foods and beverages containing processed carbohydrates not only taste sweeter but also are less expensive and more accessible than those containing natural carbohydrates [2].

A hallmark of childhood is the liking for all that tastes sweet. Sweet-tasting carbohydrates comprise a significant portion of the daily energy intake of American children [3•]. However, today's children favor foods with processed carbohydrates (e.g., foods and beverages with sugars added by manufacturers) to foods with natural carbohydrates (e.g., fruits): 86% of 2–3-year-old children consume some type of sweetened beverage or dessert in a day [4•], whereas 80% of children do not meet recommendations for fruit intake [5]. Intakes of added sugars and sugar-sweetened beverages have risen consistently among all age groups over the last two decades [6,7],

despite research showing high consumption of processed carbohydrates is associated with increased risk for cardiovascular disease [8] and recommendations from health organizations to reduce or eliminate the amount of added sugars and sugar-sweetened beverages from the diets of all Americans, including children (e.g., [9–11]).

How can we account for patterns of food choice that seem antithetical to health and for difficulties in changing them? In this essay, we describe two factors that conspire to predispose many individuals to consume diets that are rich in sweet-tasting foods and beverages: (1) innate, evolutionarily driven taste preferences that are magnified during childhood; and, (2) consequences of repeated exposure to highly processed, intensely sweet foods, which are abundant and heavily marketed within the food supply. This review serves as a foundation for a discussion on the physiological and motivational properties of sugars. But first, we provide an overview of the molecular and neural mechanisms underlying sweet taste perception and liking.

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## The basic biology of sweet taste

Evolution has shaped the types of foods initially preferred or rejected by children [12••]. Sensory systems

evolved to detect and prefer the once rare calorie-rich foods that taste sweet (and the mineral-rich foods that taste salty) and to reject the potentially toxic ones that taste bitter. These responses are intensified during childhood and, we argue, reflect the nutritional problem of attracting children to foods that contain energy, minerals, and vitamins (e.g., mother's milk, fruits) during periods of maximal growth [13,14].

In recent years, major scientific progress has been made in identifying the initial events in sweet taste recognition (the milestones of this discovery have recently been summarized in [15<sup>•</sup>]) and the brain mechanisms underlying the strong hedonic responses experienced after tasting something sweet [16<sup>•</sup>]. G-protein-coupled receptors play a prominent role in taste recognition, activating taste cells to send electrical messages to the brain. In humans, two receptors, encoded by the *TAS1R2* and *TAS1R3* genes, act in pairs to detect molecules imparting sweet taste qualities. Variations in these genes have been shown to predict taste sensitivity to both nutritive (e.g., sucrose) and non-nutritive (e.g., sucralose, acesulfame-K) sweeteners [17] and to affect habitual consumption of sugars [18<sup>•</sup>].

Sweet taste receptors are expressed not only in the mouth but also in other areas, particularly the gut and pancreas [19–21]. These peripheral receptors do not distinguish between nutritive and non-nutritive sweeteners when these compounds are equated for sweetness [21] and stimulation of these receptors by a sweet substance stimulates nutritive processes such as the uptake of glucose [22] and release of gut hormones [23<sup>•</sup>]. Further, the taste system is a peripheral target of factors involved in appetite regulation; for example, leptin (an anorexigenic factor) suppresses, whereas endocannabinoids (orexigenic factors) enhance, sweet taste responses at cellular and behavioral levels [24]. Thus, the 'sense' of taste controls one of the most important decisions an animal makes – whether to reject a foreign substance or to take it into the body. Then, upon ingestion, this sense is 'in communication' with the gastrointestinal and central nervous systems, providing information about the quality and quantity of the impending rush of nutrients and perhaps playing an important role in regulating energy homeostasis. This system evolved in response to nutritive sweeteners and the consistent pairing of sweetness with energy sources; recent research has suggested non-nutritive sweeteners, which are intensely sweet but devoid of calories, may disrupt the balance between taste receptor action, nutrient assimilation, and appetite [25].

The emotions experienced upon tasting something sweet are complex processes mediated by taste receptors in the periphery and by multiple brain substrates, which

## Key points

- Two factors conspire to predispose some individuals to consume diets high in sweet tastes: innate taste preferences that are magnified during childhood, and repeated exposure to abundant, highly processed, sweetened foods; understanding their respective contributions is important for developing strategies to promote healthy eating habits.
- Variations in genes coding sweet taste receptors can affect how sensitive someone is to nutritive (e.g., sucrose) and non-nutritive (e.g., sucralose) sweeteners.
- In addition to the mouth, sweet taste receptors are expressed in the gut as part of a nutrient feedback system. Because these receptors do not distinguish between nutritive and non-nutritive sweeteners, ingesting a highly sweet food that is devoid of calories may dysregulate appetitive processes.
- Tasting something sweet activates the same pleasure-generating brain circuitry involved in the addictions of several drugs. Sweet taste acts as an analgesic for infants and some children but not for adults, children exhibiting depressive symptomatology, or overweight children.
- The sense of taste has an inherent plasticity: beginning very early in life, sensory experiences can shape and modify flavor and food preferences, including preferences for sweet tastes – the matrix within which sweet taste experiences occur are important and children learn which foods should and should not taste sweet through repeated exposure and familiarization.

phylogenetically are remarkably well conserved [26]. Tasting something sweet leads to the activation of pleasure-generating brain loci that are associated with reward. Brain circuitry involved in the hedonic impact of sweets is the same or overlaps with the circuitry mediating the addictive nature of drugs such as alcohol and opiates [16<sup>•</sup>]. These drugs appear to be co-opting neural pathways originally designed for seeking sweet tastes, man's oldest natural reward [27]. These pathways facilitate a strong attraction to the intensely sweet, processed carbohydrates that comprise a large portion of the American food supply and intense nutritive and non-nutritive sweeteners can be seen as supernormal stimuli with the potential to override normal behaviors [28].

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## Innate preference for sweet

The machinery needed to detect and respond to tastes is well-developed before birth and continues to mature postnatally [29]. Specialized taste cells first appear in the human fetus at 7–8 weeks, and morphologically mature receptor cells are recognizable at 13–15 weeks.

Taste buds are capable of conveying gustatory information to the central nervous system by the last trimester of pregnancy, and this information is available to systems organizing changes in autonomic activity, sucking, as well as facially expressive and other affective behaviors.

### **Infants**

Several lines of evidence show that the sensory pleasantness derived from tasting something sweet has an innate basis (see [27] for review). First, the ability to detect sweet tastes is functioning and interacting with systems controlling affect even before birth: premature infants born as early as the 33rd gestational week suck at a faster and stronger rate in response to a sweet-flavored nipple compared to an unflavored nipple. Second, newborn infants show increased heart rate when a sweet-tasting substance is in the oral cavity. Third, newborns differentiate varying degrees of sweetness and will consume a greater volume of a solution that tastes sweeter [30]. Finally, infants' faces relax in response to placement of a sweet solution in the oral cavity, and this relaxation is often accompanied by a smile, resembling satisfaction [26,31]. These behavioral responses to sweet-tasting solutions are reflex-like and unlearned.

### **Children**

Both cross-sectional [32\*,33\*,34] and longitudinal [35] studies demonstrate that, although humans generally prefer sweets, there are age-related differences in the intensity of sweetness most preferred. In a recent study of 930 participants, children selected a 0.54-mol/l sucrose concentration as their most preferred [32\*], a concentration higher than that preferred by adults and equivalent to 11 teaspoons (about 44 g) of sugar in an 8-oz. glass of water (nearly twice the sugar concentration of a typical cola). The intensity of children's most-preferred sweetness, as measured in the laboratory, has real-world significance as it relates significantly to their preferred levels of sugar in beverages [32\*,34] and cereals [32\*,34,36].

Among all age groups, there are individual differences in sweet preferences that can be due to a variety of factors including early experience (see below), genetics, race/ethnicity, medication use, nutritional deficiencies, metabolic changes, otitis media, and addictions (e.g., [33\*,37,38]). However, the positive hedonic response to sweet taste and the preference for a greater intensity of sweetness among children than adults is universal, with findings replicated across several different countries and cultures: North America [32\*,33\*,34,35], Mexico [39], Brazil [40], the Netherlands [41], France [42], Iraq [43], and Israel [31]. The age-related decline in the intensity of sweetness most preferred, which occurs during adolescence [35], may be a developmentally normative process, as it has been observed in other mammals [44]. Although the reason for this decline remains unknown, two

plausible hypotheses, not mutually exclusive, have been proposed for this decline. First, children have a higher threshold for sweet taste than adults, thus requiring larger quantities of sugar to obtain the same sweet taste experience as adults; evidence for this hypothesis is lacking. Second, growing children's high need for calories drives their preference for sweet foods, as sweetness signals energy. Although evidence for this hypothesis is also limited, one recent cross-sectional study showed that 11–15-year-old children who preferred a higher concentration of sucrose exhibited greater rates of linear growth (as indicated by urine levels of type I collagen cross-linked N-telopeptides, a metabolite produced during bone turnover) than children who preferred a lower concentration of sucrose [13]. Longitudinal studies are needed to further explore and understand the mechanisms underlying age-related changes in sweet preferences.

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### **Early-life experiences can modify preferences**

Functional plasticity is one of the defining characteristics of the developing brain and highlights the ability to change behavior based on experience. The sense of taste has an inherent plasticity: beginning very early in life, sensory experiences can shape and modify flavor and food preferences [45], including the strong liking that children have for sweet taste. Like other sensations, the sensation of sweetness is context dependent and can acquire meaning through associative learning (see [46] for review).

### **The fetal environment**

Learning about tastes and flavors begins long before experience with solid foods. The tastes and flavors of the mother's diet are transmitted through the amniotic fluid and breast milk [47], and children show preferences for flavors to which they were repeatedly exposed during the prenatal and postnatal periods [45].

There is evidence to suggest that prenatal factors, such as undernutrition or overnutrition, also influence offspring eating behaviors and health outcomes, again suggesting that learning and/or programming occurs prior to birth [48]. With regards to undernutrition, women who were born severely growth restricted, a marker for adverse fetal conditions, had higher carbohydrate intakes than women who were not [49]. With regards to overnutrition, the high levels of glucose experienced by the fetuses of dams with gestational diabetes led to disturbances in the differentiation and organization of hypothalamic centers involved in body weight and metabolism [50]. There is also evidence that gestational diabetes is associated with greater cravings and preferences for intensely sweetened foods in pregnant mothers [51]; whether this condition affects the sweet taste preferences of their offspring remains unknown.

### **The child's environment**

Although the heightened preferences for sweetness in beverages and foods appear to reflect a common biological drive among children, experience is a means of tuning the taste system to respond more strongly to stimuli that are relevant to an individual's environment. Longitudinal studies revealed that babies who were routinely fed sweetened water during the first months of life exhibited a greater preference for sweetened water compared to those who had little or no experience with sweetened water [52]. A more recent cross-sectional study on 6–10-year-old children revealed that such early feeding practices may have longer-term effects on the preference for sweetened water than previously realized [53].

When children were repeatedly exposed to a sweetened orange-flavored beverage for 8 consecutive days during their daily mid-morning snack, they not only gave higher preference rankings for the beverage, but also drank more of it at the end of the exposure period [41]. Although children will prefer the level of sweetness to which they have been repeatedly exposed in a beverage or food, there are no compelling data to suggest that such repeated exposure results in a heightened hedonic response to sweetness in general. Rather, the matrix in which the sweet taste experience occurs is an important factor. Through familiarization, children develop a sense of what should, or should not, taste sweet.

Since the mid-1990s, food manufacturers have introduced more than 600 new food products that are marketed directly to children, most of which are candy and sweet snacks [54]. More research is needed to determine the extent to which marketing and availability of sweetened foods affects children's preferences [55,56], as well as their expectation that certain foods should taste intensely sweet.

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### **Sweet taste analgesia**

The liking for sweets may also have its roots in the pain-reducing properties of sugars, which, along with preferences for a more intense sweet taste, may be an identifying feature of childhood (see [27] for review). A sweet-tasting solution placed in an infant's oral cavity can reduce responses to painful stimuli, such as single or repeated heel lances [57••]. The mechanism of action appears to be that sweet taste perception mediates both endogenous opioid and nonopioid systems to block pain afferents, thus reducing stress and cardiac changes in response to painful stimuli [58]. Because noncaloric sweet substances such as aspartame mimic the calming effects of sucrose [59] and because the administration of sucrose by direct stomach loading is not effective [60], afferent signals from the mouth, rather than gastric or metabolic changes,

appear to be responsible for the analgesic properties of sweet tastes. This ability for sweet taste to act as an analgesic continues throughout childhood [33•,61] but is not evident during adulthood [61].

### **Depression and obesity renders sucrose analgesia ineffective**

The presence of a concentrated sucrose solution (0.70 mol/l), but not water, in the oral cavity increased children's pain tolerance when undergoing the cold pressor test, a cold-induced pain stimulus test [33•,61]. The more children liked this concentration of sucrose, the better it worked for increasing pain tolerance during the test [61]. However, sucrose was not an effective analgesic for children exhibiting depressive symptomatology [33•] or for overweight children [61], despite the finding that children who were depressed reported a greater liking for sweet-tasting foods and candies.

Several explanations, not mutually exclusive, are presented. First, painful stimuli may elicit more emotional stress and increased affective processing in depressed or obese children, thus impairing abilities to modulate the experience of pain [62]. Second, depressed or obese individuals may have an altered brain reward system [63] that needs a more intense sensation of sweetness to release dopamine to levels high enough to compensate for the anhedonia and reduced sensitivity to reward associated with these conditions. Last, greater sweet food liking by depressed children may lead to more frequent indulgences in sweets, which in turn could affect the ability of sucrose to act as an analgesic; animal model studies have shown that excessive sugar intake alters the efficacy of sucrose as an analgesic [64]. The role that dietary habits and individual differences contribute to the preferences for sweet taste and its physiological consequences in children is an important area for future research.

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### **Conclusion**

In the USA, consumption of sweet-tasting carbohydrates far exceeds recommended levels, with children and adolescents consuming a significant portion of total energy from added sweeteners [3•,7]. Children's innate and learned reactions to sweet taste provide insight into why they are so drawn to sweet tastes, and why this preference is so resistant to change, especially in the modern food environment.

Preference for intensely sweet tastes during development may have ensured the acceptance of nature's first food – mothers' milk – as well as nature's sweet-tasting foods (e.g., fruits), which contain energy, minerals, and vitamins. However, today's food supply is characterized

by an abundance of nutrient-poor, highly concentrated sugars in foods and beverages, as well as non-nutritive sweeteners that may disrupt the balance between taste, nutrients, and appetite [25].

Sweet tastes act as an analgesic during childhood but there are striking individual differences in the levels of sweetness preferred and the effectiveness of sweet tastes as an analgesic. Therefore, it is important to realize that attempts to limit consumption of sweet foods and beverages may be more difficult for some individuals because individuals differ in the inherent hedonic value of sweet tastes and how sweets make them feel. More knowledge about the factors that contribute to preferences for sweet-tasting foods and beverages in children, who today struggle with obesity and diabetes more than any previous generation, may elucidate population-based strategies to overcome diet-induced disease and promote healthy eating habits.

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Additional references related to this topic can also be found in the Current World Literature section in this issue (p. 416).

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