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The sweetness and bitterness of childhood: Insights from basic research on taste preferences

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HIGHLIGHTS

- Children's liking of sweet and dislike of bitter reflect their basic biology.
- Preferences for sweets and sensitivity to bitter change during adolescence.
- Levels of sweet taste most preferred have remained stable during the past decade.
- Sodium salts are more likely to block bitter tastes in adults than children.
- For children, sugars are a better blocker of some bitter tastes than are salts.

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ABSTRACT

In this article, we review findings from basic, experimental research on children that suggest that the liking of sweet and the dislike of bitter tastes reflect children's basic biology. Children are born preferring sweet tastes, which attract them to mother's milk and even act as an analgesic. They prefer higher levels of sweet than do adults, with preferences declining to adult levels during middle to late adolescence, which coincides with the cessation of physical growth. The level of sweetness most preferred by children has remained heightened relative to adults for nearly a decade, despite reductions in sugar, both consumed and in the food environment. In spite of these reductions, however, children's intake of sugar remains higher than that recommended by health organizations worldwide. In contrast to sweet taste, children dislike and reject bitter taste, which protects them from ingesting poisons. Although variation in bitter taste receptor genes such as *TAS2R38* accounts for people's marked differences in perceptions of the same bitter-tasting compounds, basic research revealed that these genotype–phenotype relationships are modified with age, with children of the same genotype being more bitter sensitive than adults and the changeover occurring during mid-adolescence. This heightened bitter sensitivity is also evident in the taste of the foods (green vegetables) or medicines (liquid formulations of drugs) they dislike and reject. While bitter taste can be masked or blocked to varying degrees by sugars and salts, their efficacy in modulating bitterness is not only based on the type of bitter ligand but on the person's age. Children's heightened preference for sweet and dislike of bitter, though often detrimental in the modern food environment, reflects their basic biology. Increasing knowledge of individual variation in taste due to both age and genetics will shed light on potential strategies to promote healthier eating since chronic diseases derive in large part from poor food choice dictated by taste preferences, and will contribute to a new era of drug formulations designed especially for the taste palate of children.

1. Introduction

Sweet tasting candies have been the first purchase children have made with their own money since the 19th century [1]. Removing the medicines from the colorful drops of flavored sugar typically found in druggists' stocks resulted in "penny candies"—the first confections to reach a mass audience in America, specifically targeted to working-class children who could afford the occasional penny's worth of bliss [2]. It's no surprise that easy access to cheap candy, manufactured on readily available machinery from inexpensive sugar, was a marketing success—children's proclivity for sweetness, not to mention its use to "make the medicine go down," is universal and evident among cultures around the world. In this article, we review findings from basic, experimental research in children that suggest that the liking of sweet taste and the dislike of bitter taste are not solely a product of modern-day technology and advertising, but are reflective of children's basic biology.

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The sense of taste, of which sweet and bitter are just two of the five modalities (which also include sour, salty, and umami), can be a source of pleasure or pain and serves as gatekeeper to ensure that animals correctly make one of the more important decisions they face: whether to accept or reject a food or liquid. The liking of sweet and rejection of bitter represent inborn responses, yet there is inherent plasticity in these senses—our biology is not necessarily our destiny. We acknowledge that, in the scientific research on the ontogeny of these diverse tastes, each psychophysical measure has its limitations. However, a convergence of findings suggests that the ability to detect tastes is present early in ontogeny [3], is remarkably well conserved phylogenetically [4], and that this ability can modulate complex behaviors, including dietary choices, throughout the life span [5].

1.1. Sweet: the taste of pleasure

The sensations experienced when tasting something sweet are mediated by taste receptors in the periphery and by multiple brain substrates [6,7] which are associated with reward-related learning and behaviors [8]. Taste receptor cells produce proteins that participate in sweet taste transduction, and some of these proteins are inserted into the cell membrane to form taste receptors [9]. Two proteins, T1R2 and T1R3 (taste receptor family 1, proteins 2 and 3), combine to create a sweet receptor; their associated genes are *TAS1R2* and *TAS1R3*.

Several lines of evidence indicate that the liking for sweet taste is inborn. Before birth, the ability to detect sweet tastes is functioning and interacting with systems controlling affect and suckling [10]; thus, babies are born able to detect and prefer the predominant taste quality of the food they need to survive: mother's milk. Newborns respond to even dilute sweet tastes, differentiate varying degrees of sweetness, and, given the choice, will consume more of a sugar solution than water [11,12]. When a sweet solution is placed in the oral cavity, the infant's face relaxes, resembling an expression of satisfaction that may be followed by a smile [4,13,14]. Two- to 3-day-old infants respond to sucrose administration with asymmetrical brain electrical activity usually associated with hedonically positive emotional reactions or approach behavior [15]. Autonomic responses vary according to the behavioral state of the infant: when increasing concentrations of sucrose were placed in the mouths of calm infants, their heart rates increased proportionally [16], but when sweet tastes were introduced to agitated infants, their heart rates decreased, resulting in overall calmness [17].

Perhaps most investigated in the ontogeny of human sweet perception is the ability of sweet tastes to act as an analgesic in infants and children. Small amounts of a sweet solution placed on the tongue of a crying newborn exert a rapid, calming effect that persists for several minutes [18,19]. Because non-caloric sweet substances such as aspartame mimic the calming effects of sucrose [19], and because the administration of sucrose by direct stomach loading is not effective [20], it appears that afferent signals from the mouth, rather than metabolic or gastric changes, are responsible for the analgesic properties of sweet tastes. Recent systematic reviews on this body of research concluded that administration of sweet tastes is safe and effective for reducing procedural pain in infants from single painful events such as heel lance, venipuncture, and circumcision in the short term [21].

The ability of sweet tastes to reduce pain continues during childhood, as evidenced by the finding that the presence of sucrose, but not water, in the oral cavity delayed 8- to 11-year-old children's reporting of pain onset when undergoing a cold-induced pain stimulus test [22–24]. Sucrose's efficacy in reducing pain is related to the hedonic value of sweet taste for the child: the more children like sucrose, the better it works in increasing pain tolerance [24].

Children as young as 3 years of age are capable of participating in psychophysical tasks that measure the levels of taste most preferred. In 1990, a method for measuring an individual's most preferred level of salty taste was developed at the Monell Center [25], and later adapted for sweet taste and included in the NIH Toolbox [26]. In age-related comparisons, the same forced-choice, paired-comparison tracking method [27] is used for both pediatric and adult populations. This body of both longitudinal and cross-sectional research consistently reveals that the most preferred concentration of sweet taste remains heightened throughout childhood (~0.54–0.60 M sucrose) and does not decline to adult levels until middle to late adolescence [27,28]. To put this in perspective, a 0.60 M sucrose concentration is equivalent to ~12 teaspoons (4 g per teaspoon) of sugar in 230 ml of water (8 ounce. glass), whereas a typical cola has a 0.34 M sugar concentration (~7 teaspoons in 8 oz. of water, which is closer to adults' level of most preferred sweetness).

Data collected from two separate populations of children and adults, using the same methods but almost a decade apart, highlight the stability of the age-related bliss point in sweet tastes. These two study populations consisted of: (1) 244 children (5–10 years) and 235 adults (22–52 years) who participated in research studies at the Monell Center in 2002–2003 (33.4% white, 53.7% black, 12.9% other/more than one race), and (2) 109 children (5–12 years) and 83 adults (20–56 years) who participated in 2010 (31.4% white, 48.2% black, 20.4% other/more than one race). To measure the most preferred level of sweet taste, we used a 2-series, forced-choice tracking method (see [27] for more details). All procedures were approved by the Office of Regulatory Affairs at the University of Pennsylvania and informed consent was obtained from each adult or parent of child and assent obtained from those children seven years and older.

The age-related differences in most preferred level of sweetness were remarkably consistent between 2002 and 2010, despite changes in overall sugar intake (i.e., both added sugar and dietary sugar inherent to fruit and dairy products) among both children and adults over this time period. As shown in Fig. 1, children, on average, most preferred a 0.54–0.56 M whereas adults most preferred a 0.42–0.44 M sucrose solution. Although self-reported dietary recall data has its limitations [29], NHANES data collected over 2-year periods from 2001 to 2011 showed reductions in sugar consumption among both children (2–11 years) and adults (20–59 years) by more than 15 g per day (2001–2002 [30], 2003–2004 [31], 2005–2006 [32], 2007–2008 [33], 2009–2010 [34], 2011–2012 [35]). Consistent with these data, food supply data from the Food and Agriculture Organization of the United Nations indicate a reduction of sugars available in the American food supply of approximately 7 kg per capita over the same period [36]. That the level of sweetness most preferred by children remained heightened relative to adults over nearly a decade despite reductions in sugar both consumed and in the food environment, provides further evidence that sweet preferences are largely driven by basic biology. It is important to note, however, that although the consumption of sugars declined over time, intakes continue to exceed recommended limits [37]. Moreover, how much sugar is in the child's diet may not be a good proxy for its overall level of "sweetness" given the increased use of non-nutritive sweeteners in the food supply, especially in foods geared for children.

What causes the age-related decline in sweet preference and consumption between childhood and adulthood remains a mystery, but it has been observed in other mammals [38]. One hypothesis is that heightened sweet preference early in life may be linked to the growing child's need for calories [39], which is supported by recent findings [40]. Coldwell and colleagues divided 11- to 15-year-olds into 'high' and 'low' sweet preference groups based on their sucrose preferences [40]. Although the groups did not differ in sucrose detection thresholds, age, body mass index, percent body fat, or pubertal development, they did differ in levels of N-telopeptides of type I collagen (NTx), a biomarker for bone resorption and growth [41] that is higher during growth spurts. NTx levels were significantly lower in the low sweet preference group than in the high sweet preference group, suggesting that the age-related decline in sucrose preferences may be related to the cessation of physical growth [40].