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.

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.

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•]) and the brain mechanisms underlying the strong hedonic responses experienced after tasting something sweet [16•]. 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•].

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•]. Further, the taste system is a peripheral target of factors involved in appetite regulation; for example, leptin (an anorexigenic factors) 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 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•]. 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].

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.

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.

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.

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.

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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There are no conflicts of interest.

References and recommended reading

Papers of particular interest, published within the annual period of review, have been highlighted as:

- • of special interest
- •• of outstanding interest

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

1 Popkin BM, Nielsen SJ. The sweetening of the world's diet. Obes Res 2003; 11:1325–1332.

2 Drewnowski A. Fat and sugar: an economic analysis. J Nutr 2003; 133:838S–840S.

3 • Reedy J, Krebs-Smith SM. Dietary sources of energy, solid fats, and added sugars among children and adolescents in the United States. J Am Diet Assoc 2010; 110:1477–1484.
A recent survey of the dietary intakes of American children and adolescents. This study uses NHANES 2003–2004 and 2005–2006 data to identify the top sources of energy for children aged 2–18 years.

4 • Fox MK, Condon E, Briefel RR, *et al.* Food consumption patterns of young preschoolers: are they starting off on the right path? J Am Diet Assoc 2010; 110:S52–S59.
This study presents data from the 2008 Feeding Infants and Toddlers Study, which describes the dietary patterns of 2–3-year-old Americans. The vast majority of young children consumed sugar-sweetened beverages, desserts, and sweet or salty snacks on a daily basis.

5 Krebs-Smith SM, Guenther PM, Subar AF, *et al.* Americans do not meet federal dietary recommendations. J Nutr 2010; 140:1832–1838.

6 Wang YC, Bleich SN, Gortmaker SL. Increasing caloric contribution from sugar-sweetened beverages and 100% fruit juices among US children and adolescents, 1988–2004. Pediatrics 2008; 121:e1604–e1614.

7 Guthrie JF, Morton JF. Food sources of added sweeteners in the diets of Americans. J Am Diet Assoc 2000; 100:43–51; quiz 49–50.

8 Welsh JA, Sharma A, Cunningham SA, Vos MB. Consumption of added sugars and indicators of cardiovascular disease risk among US adolescents. Circulation 2011; 123:249–257.

9 American Academy of Pediatrics Committee on School Health. Soft drinks in schools. Pediatrics 2004; 113:152–154.

10 US Department of Agriculture, US Department of Health and Human Services. Dietary Guidelines for Americans, 2010. Washington, DC; 2010.

11 Koplan JP, Liverman CT, Kraak VA, editors. Preventing childhood obesity: health in the balance. Washington, DC: National Academies Press; 2005.

12 •• Reed DR, Knaapila A. Genetics of taste and smell poisons and pleasures. Prog Mol Biol Transl Sci 2010; 94:213–240.
This is an excellent and timely review of taste and smell genetics and hedonics.

13 Coldwell SE, Oswald TK, Reed DR. A marker of growth differs between adolescents with high vs. low sugar preference. Physiol Behav 2009; 96:574–580.

14 Drewnowski A. Sensory control of energy density at different life stages. Proc Nutr Soc 2000; 59:239–244.

15 • Yarmolinsky DA, Zuker CS, Ryba NJ. Common sense about taste: from mammals to insects. Cell 2009; 139:234–244.
This is an excellent review that summarizes scientific discoveries on the anatomical and molecular mechanisms underlying taste sensations.

16 • Berridge KC, Ho C-Y, Richard JM, DiFeliceantonio AG. The tempted brain eats: pleasure and desire circuits in obesity and eating disorders. Brain Res 2010; 1350:43–64.
This is an excellent review of the brain reward mechanisms that generate 'wanting' and 'liking' of foods, and how disruption of these mechanisms may contribute to the development of obesity and eating disorders.

17 Nelson G, Hoon MA, Chandrashekar J, *et al.* Mammalian sweet taste receptors. Cell 2001; 106:381–390.

18 • Eny KM, Wolever TM, Corey PN, El-Sohemy A. Genetic variation in TAS1R2 (Ile191Val) is associated with consumption of sugars in overweight and obese individuals in 2 distinct populations. Am J Clin Nutr 2010; 92: 1501–1510.
This study illustrated that variation in the *TAS1R2* gene was associated with interindividual differences in sugar consumption. The implications of these findings for the success or failure of improving dietary intake patterns are discussed.

19 Margolskee RF, Dyer J, Kokrashvili Z, *et al.* T1R3 and gustducin in gut sense sugars to regulate expression of Na+-glucose cotransporter 1. Proc Natl Acad Sci U S A 2007; 104:15075–15080.

20 Sclafani A. Sweet taste signaling in the gut. Proc Natl Acad Sci U S A 2007; 104:14887–14888.

21 Jang HJ, Kokrashvili Z, Theodorakis MJ, *et al.* Gut-expressed gustducin and taste receptors regulate secretion of glucagon-like peptide-1. Proc Natl Acad Sci U S A 2007; 104:15069–15074.

22 Mace OJ, Affleck J, Patel N, Kellett GL. Sweet taste receptors in rat small intestine stimulate glucose absorption through apical GLUT2. J Physiol 2007; 582:379–392.

23 • Kokrashvili Z, Mosinger B, Margolskee RF. Taste signaling elements expressed in gut enteroendocrine cells regulate nutrient-responsive secretion of gut hormones. Am J Clin Nutr 2009; 90:822S–825S.
This review chronicles the scientific progress of the research that examines the presence and function of taste receptors in the gut.

24 Yoshida R, Ohkuri T, Jyotaki M, *et al.* Endocannabinoids selectively enhance sweet taste. Proc Natl Acad Sci U S A 2010; 107:935–939.

25 Egan JM, Margolskee RF. Taste cells of the gut and gastrointestinal chemosensation. Mol Interv 2008; 8:78–81.

26 Steiner JE, Glaser D, Hawilo ME, Berridge KC. Comparative expression of hedonic impact: affective reactions to taste by human infants and other primates. Neurosci Biobehav Rev 2001; 25:53–74.

27 Pepino MY, Mennella JA. Children's liking of sweet tastes: a reflection of our basic biology. In: Spillane W, editor. Optimising sweet taste in foods. Cambridge: Woodhead Publishing; 2006. pp. 54–65.

28 Lenoir M, Serre F, Cantin L, Ahmed SH. Intense sweetness surpasses cocaine reward. PLoS One 2007; 2:e698.

29 Ganchrow JR, Mennella JA. The ontogeny of human flavor perception. In: Doty RL, editor. Handbook of olfaction and gustation. 2nd ed. New York: Marcel Dekker; 2003. pp. 823–946.

30 Desor JA, Maller O, Turner RE. Taste in acceptance of sugars by human infants. J Comp Physiol Psychol 1973; 84:496–601.

31 Steiner JE. Facial expressions of the neonate infant indicating the hedonics of food related chemical stimuli. In: Weiffenbach JM, editor. Taste and development: the genesis of sweet preference. Washington, DC: Government Printing Office; 1977. pp. 173–189.

32 Mennella JA, Lukasewycz LD, Griffith JW, Beauchamp GK. Evaluation of the
• Monell forced-choice, paired-comparison tracking procedure for determining sweet taste preferences across the life span. Chem Senses 2011. [Epub ahead of print]
This study identifies factors associated with individual differences in sweet preferences across the lifespan. It also describes a validated method that can be used to determine the intensity of sweetness most preferred.

33 Mennella JA, Pepino MY, Lehmann-Castor SM, Yourshaw LM. Sweet
• preferences and analgesia during childhood: effects of family history of alcoholism and depression. Addiction 2010; 105:666–675.
This recent study in children revealed that the co-occurrence of having depressive symptomatology and family history of alcoholism was associated with a preference for more concentrated sweet tastes but depressive symptomatology antagonized the analgesic properties of sucrose.

34 Mennella JA, Pepino MY, Reed DR. Genetic and environmental determinants of bitter perception and sweet preferences. Pediatrics 2005; 115:e216–e222.

35 Desor JA, Beauchamp GK. Longitudinal changes in sweet preferences in humans. Physiol Behav 1987; 39:639–641.

36 Liem DG, Mennella JA. Sweet and sour preferences during childhood: role of early experiences. Dev Psychobiol 2002; 41:388–395.

37 Hayes JE, Bartoshuk LM, Kidd JR, Duffy VB. Supertasting and PROP bitterness depends on more than the TAS2R38 gene. Chem Senses 2008; 33:255–265.

38 Levine MD, Marcus MD, Perkins KA. A history of depression and smoking cessation outcomes among women concerned about postcessation weight gain. Nicotine Tob Res 2003; 5:69–76.

39 Vazquez M, Pearson PB, Beauchamp GK. Flavor preferences in malnourished Mexican infants. Physiol Behav 1982; 28:513–519.

40 Tomita NE, Nadanovsky P, Vieira AL, Lopes ES. Taste preference for sweets and caries prevalence in preschool children. Rev Saude Publica 1999; 33:542–546.

41 Liem D, de Graaf C. Sweet and sour preferences in young children and adults: role of repeated exposure. Physiol Behav 2004; 83:421–429.

42 Bellisle F, Dartois AM, Kleinknecht C, Broyer M. Perceptions of and preferences for sweet taste in uremic children. J Am Diet Assoc 1990; 90: 951–954.

43 Jamel HA, Sheiham A, Watt RG, Cowell CR. Sweet preference, consumption of sweet tea and dental caries; studies in urban and rural Iraqi populations. Int Dent J 1997; 47:213–217.

44 Bertino M, Wehmer F. Dietary influences on the development of sucrose acceptability in rats. Dev Psychobiol 1981; 14:19–28.

45 Mennella JA, Jagnow CP, Beauchamp GK. Prenatal and postnatal flavor learning by human infants. Pediatrics 2001; 107:E88.

46 Sclafani A. Oral and postoral determinants of food reward. Physiol Behav 2004; 81:773–779.

47 Mennella JA. The chemical senses and the development of flavor preferences in humans. In: Hale TW, Hartmann PE, editors. Textbook on human lactation. Texas: Hale Publishing; 2007. pp. 403–414.

48 Gluckman PD, Hanson MA, Cooper C, Thornburg KL. Effect of in utero and early-life conditions on adult health and disease. N Engl J Med 2008; 359:61–73.

49 Barbieri MA, Portella AK, Silveira PP, *et al.* Severe intrauterine growth restriction is associated with higher spontaneous carbohydrate intake in young women. Pediatr Res 2009; 65:215–220.

50 Poston L. Developmental programming and diabetes: the human experience and insight from animal models. Best Pract Res Clin Endocrinol Metab 2010; 24:541–552.

51 Belzer LM, Smulian JC, Lu SE, Tepper BJ. Food cravings and intake of sweet foods in healthy pregnancy and mild gestational diabetes mellitus: a prospective study. Appetite 2010; 55:609–615.

52 Beauchamp GK, Moran M. Dietary experience and sweet taste preference in human infants. Appetite 1982; 3:139–152.

53 Pepino MY, Mennella JA. Factors contributing to individual differences in sucrose preference. Chem Senses 2005; 30 (Suppl 1):i319–i320.

54 Nestle M. Food marketing and childhood obesity: a matter of policy. N Engl J Med 2006; 354:2527–2529.

55 Robinson TN, Borzekowski DL, Matheson DM, Kraemer HC. Effects of fast food branding on young children's taste preferences. Arch Pediatr Adolesc Med 2007; 161:792–797.

56 Dixon HG, Scully ML, Wakefield MA, *et al.* The effects of television advertisements for junk food versus nutritious food on children's food attitudes and preferences. Soc Sci Med 2007; 65:1311–1323.

57 Stevens B, Yamada J, Ohlsson A. Sucrose for analgesia in newborn infants
•• undergoing painful procedures. Cochrane Database Syst Rev (Online) 2010:CD001069.
This is a recent Cochrane review of the randomized controlled studies that evaluated the analgesic effects of sweet solutions during infancy.

58 Fernandez M, Blass EM, Hernandez-Reif M, *et al.* Sucrose attenuates a negative electroencephalographic response to an aversive stimulus for newborns. J Dev Behav Pediatr 2003; 24:261–266.

59 Barr RG, Pantel MS, Young SN, *et al.* The response of crying newborns to sucrose: is it a 'sweetness' effect? Physiol Behav 1999; 66:409–417.

60 Ramenghi LA, Evans DJ, Levene MI. 'Sucrose analgesia': absorptive mechanism or taste perception? Arch Dis Child Fetal Neonatal Ed 1999; 80:F146–F147.

61 Pepino MY, Mennella JA. Sucrose-induced analgesia is related to sweet preferences in children but not adults. Pain 2005; 119:210–218.

62 Strigo IA, Simmons AN, Matthews SC, *et al.* Association of major depressive disorder with altered functional brain response during anticipation and processing of heat pain. Arch Gen Psychiatry 2008; 65:1275–1284.

63 Martin-Soelch C. Is depression associated with dysfunction of the central reward system? Biochem Soc Trans 2009; 37:313–317.

64 Segato EN, Reboucas EC, Freitas RL, *et al.* Effect of chronic intake of sweet substance on nociceptive thresholds and feeding behavior of *Rattus norvegicus* (Rodentia, Muridae). Nutr Neurosci 2005; 8:129–140.