REVIEW

# Finding the Sweet Spot: Measurement, Modification, and Application of Sweet Hedonics in Humans

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**ABSTRACT**

Sweetness is a sensation that contributes to the palatability of foods, which is the primary driver of food choice. Thus, understanding how to measure the appeal (hedonics) of sweetness and how to modify it are key to effecting dietary change for health. Sweet hedonics is multidimensional so can only be captured by multiple approaches including assessment of elements such as liking, preference, and consumption intent. There are both innate and learned components to the appeal of sweet foods and beverages. These are responsive to various behavioral and biological factors, suggesting the opportunity to modify intake. Given the high amount of added sugar intake in the United States and recommendations from many groups to reduce this, further exploration of current hypothesized approaches to moderate sugar intake (e.g., induced hedonic shift, use of low-calorie sweeteners) is warranted. *Adv Nutr* 2021;12:2358–2371.

Keywords: hedonics, sweetness, intake, added sugars, low-calorie sweeteners

## Introduction

Eating is an extremely complex behavior governed by a wide array of constantly changing environmental (e.g., food availability, health messaging), behavioral (e.g., food choice, portion size, temporal patterns), and physiological (e.g., sensory, endocrine, neural) determinants (1). However, consumers consistently report that sensory factors are the primary driver (2). The sensory properties of foods and beverages are not only determinants of purchasing decisions (2–4), but also the most important index of interest in new foods and beverages (5). In addition, they influence whether one self-reports as having "eaten well" (2, 6), outranking other factors such as nutritional quality, ethics/sustainability, or monetary considerations. Although extraordinary events like the COVID-19 pandemic and factors that lead to food insecurity highlight the importance of access to food as a critical element in food choice, the fact that Americans spend <10% of their disposable income on food (7) indicates most have the freedom to indulge their palates.

Sweetness is a sensation that contributes to the palatability of many foods. It is increasingly derived from low-calorie sweeteners (LCSs) (8) as well as nutritive sweeteners inherent in foods or as discretionary sources that are added to foods. The latter now directly contributes a mean of 12.7% of energy for the US population $\geq$1 y of age (9). There is also an undetermined amount of energy from the addition of nutritive tabletop sweeteners to foods and beverages by consumers, and this is not accounted for in added sugar intake measurements (9). Moreover, although there is definitely evidence to the contrary (10–13), sweetness and sweeteners also reportedly promote intake by contributing to sensory variety (14, 15), appetite (16, 17), digestion (18), endocrine responses (19, 20), and by signaling food safety (21). However, even these mechanisms work in varying degrees through an effect on palatability. Sweetness and sweeteners have been associated with increased (22–24) and decreased (25–27) body weight as well as improved (28, 29) and reduced (30) diet quality. To assess the true impact of sweetness on energy intake and diet quality, it will be essential to better define and measure the impact of sweetness on food and beverage palatability. This article focuses on the

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Abbreviations used: AHA, American Heart Association; DGA, Dietary Guidelines for Americans; DGAC, Dietary Guidelines Advisory Committee; IUGR, intrauterine growth restricted; LCS, low-calorie sweetener; SSB, sugar-sweetened beverage; VAS, visual analog scale.

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effects of the hedonics of sweetness on dietary intake and is complementary to a recently published article on scaling of sweetness and dietary intake (31). This narrative review will first introduce the problem of excess sugar intake by summarizing trends in sweetener use and recommendations to moderate nutritive sweetener intake. This will be followed by a consideration of measurement issues related to sweet taste, particularly hedonics, and selected factors that influence the affective sensation. Finally, strategies to harness sweet preference to meet health recommendations of reducing sugar intake are described.

## Current Status of Knowledge

### Trends in sweetener use

#### *Added sugars.*

The US FDA defines added sugars as "sugars that are either added during the processing of foods or are packaged as such," and these include brown sugar, high-fructose corn syrup, honey, lactose, maltose, molasses, and sucrose (32). The WHO uses a slightly more precise definition of "monosaccharides and disaccharides added to foods and beverages by the manufacturer, cook or consumer, and sugars naturally present in honey, syrups, fruit juices and fruit juice concentrates" and refers to this as "free sugars" (33). Thus, added sugars are free sugars and the primary difference between the 2 terms is that free sugars include sugars that are naturally occurring in fruits and vegetables that have been mechanically disrupted. It must be emphasized that neither free nor added sugars necessarily reflect the overall sweetness level of the diet. Inherent sugars (such as those in fruit) also contribute to sweetness. In addition, LCSs add sweetness with intensities that vary between compounds by many orders of magnitude and in nonlinear ways with graded concentration (34, 35). Further, the sensory impact of added sugars may be diminished by nonsweet food components (e.g., ketchup contains added sugars but is not overtly sweet). Thus, measurement of total sweetness in the diet is not as straightforward as measuring the concentrations of compounds that impart a sweet sensation. Nevertheless, added sugars and LCS contributions can serve as a crude estimator. Trends described below depict data from nationally representative surveys of food intake in America (i.e., the NHANES).

Intake of added sugars increased between the end of the 1970s and the end of the 1990s, with the percentage of total energy from added sugars rising from 14% to 19% in American children and from 12% to 15% in American adults (36, 37). The next decade saw a 24% decline in absolute intake, as total added sugar consumption decreased from 401 kcal/d in 1999–2000 to 307 kcal/d in 2007–2008 (38). Two-thirds of this decrease was due to a reduction of sugars consumed in soft drinks (38).

In America during 2005–2008, boys between 2 and 19 y of age consumed a mean of 362 kcal added sugars/d (or 16.3% of total energy), whereas girls consumed significantly less at 282 kcal/d (or 15.5% of total energy) (39). Adolescent boys (12–19 y of age) consumed the most added sugar at nearly 450 kcal/d (or 17.5% of total energy) (39). In America from 2005 to 2010, the amount of energy consumed from added sugars was significantly higher in adult (>18 y of age) men (335 kcal/d) than in adult women (239 kcal/d), although the percentage of energy from added sugars was not different between the sexes (12.7% and 13.2% of total energy for men and women, respectively) (40). Among adults, individuals 20–39 y of age consumed the most added sugar, with a mean of 397 kcal/d in men (or 14.1% of total energy) and 275 kcal/d in women (or 14.5% of total energy) (40).

Although sugar-sweetened beverage (SSB) consumption has declined recently (41, 42), energy intake from SSBs remains high. In America, nearly two-thirds of children (43) and half of adults (44) consume $\geq$1 SSB on a given day. This results in SSBs contributing 155 kcal/d [or 41% of daily added sugar energy (39)] for children and 151 kcal/d [or 33% of daily added sugar energy (40)] for adults (42). In 2014, soft drinks provided ~60% of the SSB calories per day, whereas juice and sports/energy drinks provided ~15% and ~25% of the SSB calories per day, respectively (45). On their own, soft drinks contribute 7.1% to total energy, making them the greatest individual contributor to energy intake (46).

#### *LCSs.*

As added sugar consumption in America has decreased in recent years, LCS consumption has increased markedly (8). This is measured by proportions of consumers and use of products containing LCSs rather than actual intake in grams, because no data are available for the latter. In 1999–2000, only 8.7% of children and 26.9% of adults were LCS consumers, whereas in 2007–2008, 14.9% of children and 32.0% of adults were LCS consumers (47). However, the proportion of children and adults who are LCS consumers may be underestimated for a number of reasons, including the following: *1*) consumers may not be aware of LCSs in food or beverage products; *2*) producers and manufacturers are not required to provide information about LCS content on labels (48); and *3*) current food databases might not accurately capture the rapid changes in the food supply (49). Low- and no-calorie beverages are the main vehicle for LCS consumption, but LCSs are also now found in tabletop sweeteners, grain products, dairy products, desserts, and condiments (8, 50). It was estimated in 2009–2010 that 19.5% of American adults consumed a beverage with LCSs on a given day, whereas only 11.4% and 4.6% consumed tabletop sweeteners or foods with LCSs, respectively (51). Beverages containing LCSs now account for up to one-third of beverages consumed in America (45, 47, 48).

## Recommendations to Moderate Sweetener Intake

### Added sugars

An upper limit of 10% of total energy was recommended in the 2015–2020 Dietary Guidelines for Americans (DGA), although it was noted that for most total energy amounts, the available energy after meeting nutrient requirements was, in fact, not sufficient to allow the addition of 10% of total energy intake from added sugars (52). The evidence was reviewed again by the 2020–2025 Dietary Guidelines Advisory Committee (DGAC). They concluded that there is strong evidence that eating patterns that limit added sugars are associated with reduced risk of cardiovascular disease and moderate evidence that these eating patterns are associated with a reduced risk of obesity, type 2 diabetes, and some types of cancers (52, 53). Their recommendation was that Americans limit added sugars to <6% energy/d (9), although this limit was not adopted and the recommendation to limit added sugar intake to <10% of total energy intake was retained in the 2020–2025 DGA (53). The basis for the 6% limit was modeling that indicated it would not be possible to meet all nutrient intake goals and remain within specified total energy intake bounds with an intake of added sugars >6% of total energy for diets ranging from 1000 kcal/d to 2800 kcal/d (9). Moreover, even this value is liberal because it was based on assumptions that food choices would be more nutrient-dense than customary choices and no alcohol consumption. It was noted that there can be a tradeoff between saturated fat and added sugar, but even if no saturated fat is ingested, the limit for added sugars increases only modestly. For a diet of 2000 kcal, shifting food choice so that the proportion of saturated fat to added sugar changes from 55%:45% (the ratio of current food choices) to 0%:100% results in an increased allowance of only 132 kcal from added sugars. Thus, the allowance for added sugar is very small.

Recommendations for added sugar, by both the DGAC and other food and health organizations, are largely focused on disease prevention rather than enhancing diet quality. Energy provided by added sugars is not any more obesogenic than energy provided by other foods; however, added sugars are often consumed in foods that are energy-dense and nutrient-poor. Nearly 70% of added sugars intake comes from 5 food categories: sweetened beverages, desserts and sweet snacks, coffee and tea, candy and sugars, and breakfast cereals and bars (54, 55). In a systematic review of added sugars and diet quality, 21 of 22 studies reported an association between higher added sugar intake and poorer diet quality (56). The intake of nutrients such as thiamin, riboflavin, niacin, folate, calcium, iron, zinc, and vitamins A, B-6, and B-12 is negatively associated with added sugar intake (56). In addition, children that consume ≤10% of their energy from added sugars have significantly higher intakes of total fruit, dairy, and whole grains than children that consume >10% of their energy from added sugars (55). There are several approaches for reducing added sugars intake and concurrently improving diet quality. The selection of items from the food categories providing the majority of added sugars may be reduced, especially those with the lowest nutrient density (i.e., items that are not enriched or fortified). Second, discretionary contributions (i.e., table sweeteners) may be moderated. Third, LCSs can be substituted for discretionary nutritive sweeteners. Fourth, foods that contain high added sugars content as well as desired nutrients can be replaced with versions where LCSs substitute for the added sugars.

The influence of total dietary sweetness on diet quality is less clear, however, because total sugar intake is positively associated with calcium and vitamin C intake (56). In addition, NHANES data from 1999–2008 demonstrated that LCS consumption was associated with higher scores on the Healthy Eating Index, which is a measure of diet quality used to assess how well a set of foods aligns with DGA recommendations (29). However, consuming a "diet" version of the same nutrient-poor food product could reduce energy intake to help with weight management, but would not necessarily increase nutrient intake. Sweeteners are not consumed on their own but are, instead, part of a food or beverage that contributes to the diet. Further research is needed to better understand how sweeteners and sweet products fit into a total diet.

Several international health organizations have developed similar recommendations to the 2020–2025 DGA for added/free sugars. In 2015, the WHO recommended that free sugar intake not exceed 10% of total energy intake, with an ultimate goal of reducing free sugar intake to 5% of total energy intake (57). These recommendations were based on evidence indicating an association between sugar and body weight and dental caries. Diabetes Canada, the Scientific Advisory Council on Nutrition in England, and Healthy People 2020 followed roughly the same reasoning as the WHO and recommended similar upper limits for added sugar intake (58–60). The American Heart Association (AHA) has recommended that women and men should consume no more than 100 and 150 kcal/d, respectively, from added sugars (61). This recommendation was made by the AHA in order to "achieve and maintain healthy weights and decrease cardiovascular disease risk while at the same time meeting essential nutrient needs" (61). However, the Institute of Medicine has recommended that added sugar intake not exceed 25% of total energy intake (62), because it reports no adverse effects related to added sugar consumption below this amount.

Overall, ≥60 countries have implemented guidelines or policies in an attempt to curb sugar consumption (63). The policies implemented fall under a number of different categories, including those intended to provide information (e.g., new Nutrition Facts label that includes an amount of added sugar), restrict or eliminate choice [e.g., fewer SSBs sent to schools (64)], guide choice through (dis)incentives (e.g., SSB tax), and enable or guide choice by changing the default [e.g., the food/drink industry reduces overall sugar in products (65)]. Other reviews (36, 65, 66) have conducted a more in-depth exploration of the variety of different policies enacted to reduce sugar intake.

Americans appear to implicitly understand the importance of these recommendations, because a recent survey found that 74% of consumers claimed that they were trying to avoid or limit sugar intake (2). In fact, low sugar is currently

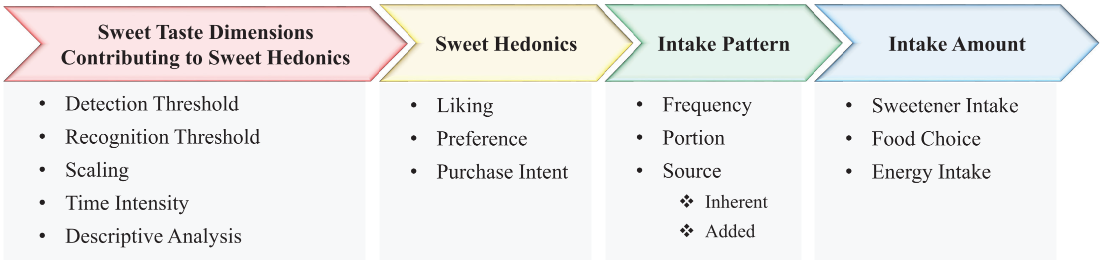


**FIGURE 1** The measurement of sweet hedonics in relation to intake pattern and amount. Detection Threshold: the lowest concentration that can be detected relative to a given background at better than chance probability. Recognition Threshold: the lowest concentration to identify quality relative to a given background at better than chance probability. Scaling: intensity ratings. Time Intensity: changes in perceived intensity over time. Descriptive Analysis: assessment of the combination of sensory attributes that characterize selected dimensions (e.g., texture) or the totality of a food's properties.

the top product claim consumers are looking for when purchasing groceries (67). Still, only ~10% of the population consumes at or below the recommended amount for added sugars (9).

### LCSs

Whereas there tends to be strong agreement that added sugar consumption should be limited, there is far less certainty surrounding recommendations for LCS consumption. The 2020–2025 DGA concluded "replacing added sugars with low- and no-calorie sweeteners may reduce calorie intake in the short-term and aid in weight management, yet questions remain about their effectiveness as a long-term weight management strategy" (53). Similarly, the AHA and American Diabetes Association published a joint statement in 2012 declaring that there are insufficient data to determine whether LCSs are useful for reducing added sugars or providing benefits to appetite, energy intake, weight management, or cardiometabolic risk factors (68). In 2018, the AHA concluded that LCS beverages may be useful for energy intake and weight control but advised against prolonged consumption of LCS beverages by children, because there is some observational evidence of potential adverse effects (e.g., risk of type 2 diabetes and stroke) (69). Public Health England states that replacing sugars with LCSs could be beneficial for energy intake and weight management (70). Alternatively, Canada's Food Guide states that LCSs are not needed for healthy eating and may actually make healthy eating more difficult because foods and drinks with LCSs may replace healthier foods or lead to a preference for sweet foods (71), although there is little direct evidence to support this claim (72). Importantly, various LCSs may have different effects on body weight, energy intake, and appetite, and it may not be appropriate to group them together, leading to uncertainties in recommendations (73).

## Sweet Taste Measurement

The sense of taste can be measured by multiple attributes including threshold sensitivity, suprathreshold intensity, temporal patterns, quality, and hedonics. The first 4 dimensions contribute important information, but their impact on feeding patterns and energy intake largely results from how that information is interpreted hedonically (74–81) (**Figure 1**). Being able to detect sweetness motivates food approach or avoidance based on whether the sensation signals the item is palatable and/or safe. However, sweet hedonics is complex, with multiple measurement approaches and each with different implications for feeding.

### Perception of sweetness

Sensitivity to sweetness and intensity judgments of sweetness are 2 distinct dimensions of sweetness measurement. Sensitivity (threshold) is a measure of the lowest limits of a stimulus concentration that can be detected (detection threshold), recognized (recognition threshold), or differentiated (discrimination threshold) under a given set of conditions (82, 83). The detection threshold is the lowest concentration of a sweetener in 1 stimulus (e.g., water, food) that permits the determination that it differs from the same vehicle without the sweetener. Thresholds are not an innate characteristic of an individual, rather they are an index of correct performance under a given set of conditions with some predetermined level of confidence. Values will vary not just under different testing conditions but also over time and with changes in a judge's attention, motivation, and physiological status. Recognition thresholds are the lowest concentrations at which a particular quality label (e.g., sweet) is reliably ascribed to the stimulus. Whereas thresholds reflect the lowest functional limits of a sensory system, intensity judgments (scaling) reveal how the magnitude of sensation from suprathreshold (above threshold) stimuli changes with stimulus concentration. Sweetness intensity sensation grows nonlinearly with increments of sweetener concentration. Typically, it increases at a rate that exceeds gradations of sweetener concentration (84). That is, except at very high concentrations, where discrimination is diminished, small changes in sweetener concentration result in disproportionately greater sweetness sensation (83). This holds important implications for determining how adjustments of sweetener concentration may affect hedonic ratings. Small additions or reductions at lower concentrations

**A** 9-point Categorical Scale

9 = like extremely
8 = like very much
7 = like moderately
6 = like slightly
5 = neither like nor dislike
4 = dislike slightly
3 = dislike moderately
2 = dislike very much
1 = dislike extremely

**B** VAS

---------|--------------------------------------------------------------------------------|--------

Dislike extremely  Like extremely

**FIGURE 2** Hedonic scales. (A) 9-point categorical scale, (B) VAS. VAS, visual analog scale.

have a larger impact on sensation than similar changes at high concentrations.

### Dimensions of hedonics and approaches to measure each

Hedonics is a multidimensional attribute defined in absolute and relative terms. Reported liking for an item is a judgment in absolute terms. In contrast, preferences are relative impressions that may be based on multiple properties such as ingredient concentrations that affect sensory quality, health beliefs [e.g., one sample is preferred over another because it is lower in sugar (regardless of taste)], brand [e.g., one source (food company, country of origin) is preferred over another], product category [e.g., one type of food (juice compared with solid food) is preferred over another], or social responsibility (e.g., one product is preferred because it has a lower carbon footprint). Preference for an item does not necessarily mean it is liked. It is possible to prefer one food/beverage over another and dislike both. Consequently, different approaches are required to measure liking and preference.

The simplest and most common method to measure liking is an "acceptability test" where the item of interest may be rated on a variety of response formats. Most commonly, liking ratings are made on categorical or visual analog scales (VASs), as shown in **Figure 2** (76, 85). The categorical scale has a limited set of response options ranging from 2 to many categories. Larger numbers of categories offer finer sensitivity of responses, but the interpretation of small differences on scales with very large numbers of categories becomes less clear (e.g., a difference of 5 units on a 10-point scale is clear, but on a 100-point category scale, it is probably not perceptually meaningful). The optimal number of categories will be a function of the types of judges conducting the assessment (e.g., cognitive function, task familiarity), level of sensitivity desired by the experimenter, and practicality of analysis. The most common scale is a 9-point scale which allows respondents to provide reasonable discrimination at each level (86) (see Figure 2A). An odd number of categories allows the development of a bipolar scale with a neutral point in the center. The strength of category scales is that they are simple and familiar response scales that can be adapted to almost any audience. A weakness is that the liking difference between 2 sequential categories at the low end of the scale may not be perceptually equal to that between 2 sequential categories at the high end of the scale. Some scales use a quasi-logarithmic distribution of categories to more closely reflect human perceptional differences across graded sensation levels (87, 88). On the other hand, VASs provide a continuous response format without the need for number assignment. Respondents are asked to place a mark along a line anchored with semantic labels at each end that reflect their impression of the liking of the food item (see Figure 2B). Ratings are interpreted by measuring the distance from a set point (typically the low anchor) to the respondent's mark. VASs are slightly more cognitively demanding, may not be practical in some settings, and can pose some additional burden in analyses, although electronic means to administer and analyze such scales are now available.

Food and beverage hedonics can also be assessed by indirect indexes such as intent to purchase, acute intake, and habitual intake (89). Purchase intent is also commonly assessed by category scales or VASs with scale descriptors such as "definitely would not buy," "would maybe buy/would maybe not buy," and "would definitely buy" (90). The assumption is that "intent" or "use" is an index of hedonics, but this is not necessarily the case because items may be consumed for a variety of reasons as long as they are not too unpalatable. In addition, purchase intent measures future intended use rather than actual usage and does not perfectly reflect liking of an item (90). Another indirect measure of liking is the acute intake of an item within a limited time, commonly measured by plate waste. Some evidence suggests this is a better predictor of liking in children (91, 92) than in adults (93, 94), for whom the contribution of nonhedonic factors in behavioral responses varies. In addition, liking may be inferred by measures of habitual intake as assessed by FFQs or dietary records (e.g., 24-h recall, 3-d food diary), but again this is an imperfect measure owing to contributions from many other factors such as cost, availability, convenience, or health beliefs. Whereas disliking is strongly related to low intake (95), the association between liking and intake is weaker (96).

Where a choice is an option, preferences can improve the predictive strength of a hedonic response, because it is possible to have a preference for one item over another despite the 2 being equally liked. In preference testing, respondents may be offered the option of indicating no preference. The advantages are that consumers with no real preference have a logical response option, and the researcher gains insight into the proportion of respondents falling into this category. When respondents are not required to make a decision, each respondent is free to adopt their own criteria as to how strong a feeling they must hold to be willing to choose one sample over the other. This characteristic introduces an uncontrolled amount of variability into the data and may mask subtle distinctions that would ultimately result in a choice of one item over another. It is also important to interpret ratings from measurements made in the laboratory cautiously because the fidelity of their translation to free-living situations where many additional, potentially confounding influences exist is uncertain.

## Innate and Learned Influences on Hedonics

### Innate influences

The common teleological explanation for the sensitivity to and liking of sweetness holds that these sensory responses developed and were conserved in the human genome during the Paleolithic period to permit hunters and gatherers to identify and ingest foods containing carbohydrate as an energy source. Human breast milk, the sole source of nutrition in early life, contains lactose, a weak sweetener, which may have contributed to the acceptance of breast milk, but the importance of this purported role is unknown. Infants with an intolerance to cow milk and other intact proteins will consume bitter casein hydrolysate formulas if this is the only option. Postweaning, overwhelmingly the availability of carbohydrates would have been in the form of starch, which humans may have some limited capacity to detect (97, 98), but is not sweet. The most effective sweet taste stimuli, such as glucose and sucrose, would have been extremely rare and, when encountered, would have been primarily in energy-dilute sources such as fruits (honey is the exception). Thus, the functionality of sweetness as an inherent determinant of food choice in early hominins is open to question (99).

Sensitivity to sweetness is present in utero (100) and its palatability is demonstrable in neonates (101). Interpreting the hedonic valence of stimuli in these types of trials is problematic. However, similar studies with stimuli rated as pleasant and unpleasant by adults indicate reactions are similar across the lifespan. When saccharin, a sweet substance, is injected into the amniotic fluid, there is an increase in fetal drinking (100). This is in contrast to a decrease in fetal drinking with exposure to lipiodol, a bitter substance (102). In addition, whereas newborns pucker and lick their lips and relax their faces after exposure to sweetness, sour and bitter tastes lead to a gaping response and salivation to dilute and expel the unpleasant stimulus (101). Sweetness is also rewarding to newborns. When exposed to a sweetened gelatin nipple, newborns suck harder and take fewer, shorter pauses than when they are provided an unsweetened latex nipple (103).

### Learned influences

There is a well-documented innate basis for individual variability in perceived bitterness of selected compounds (104), but this is not the case for sweetness. Still, there is marked interindividual variability in the preferred level of sweetness of foods and preference for foods that are predominantly sweet compared with savory (105). This reflects a contribution of early and ongoing learning, which starts before birth. Flavors from the mother's diet are transmitted in the amniotic fluid and breast milk (106, 107). Therefore, what the mother eats during pregnancy and lactation can influence the child's flavor preferences (106). Whether the mother's diet influences liking and preference for sweetness is unknown.

There has been some evidence for associative learning about sweetness hedonics in infants. Repeated exposure to sweetness leads to a heightened preference for sweetness (108, 109). Infants who were repeatedly exposed to sugar water consumed more sugar water later in life than those who were not repeatedly exposed to sugar water (110). However, this was specific to the sugar water consumed as an infant, because they did not consume more of a fruit-flavored sugar water later in life. Thus, the associative learning was specific to the food source rather than total sweet food intake. Similar findings were observed in children whose mothers routinely added sugar to their foods (109). Another study reported children who were provided a sweet drink for 8 d developed a preference for sweeter foods generally (111), but long-term effects of sweetness exposure on hedonics are unclear (112). Repeated exposure to flavors in children may inform them which flavors are appropriate in a given food context (111). As opposed to learning through adding flavors into the diet, work with salt and fat demonstrates that the preferred level of these sensory stimuli in foods can be manipulated by reducing sensory exposure to the sensations they impart (113, 114). This is discussed in more detail in the "Approaches to modify sweet hedonics" section.

## Individual Variability in Sweet Hedonics and Energy Intake

An innate liking for sweetness is well established (108, 115–117), but this is not a strong determinant of liking of sweet foods or beverages or preferred sweetness levels of specific foods. Sensitivity to sweetness varies between individuals (82, 118) and there is a substantive contribution of learning and social custom to liking (76, 77, 119). For example, within practical limits, liking of sweet beverages has been reported to be inversely associated with its sweet intensity (79, 119), whereas liking of cookies and ice cream has been reported to be positively correlated with sweet intensity (119). Furthermore, preferred sweetness intensity differs between ethnic groups generally and for specific foods (77). Differences may also reflect the various roles sweeteners play in foods and how these properties are valued. Sweeteners also contribute to flavor profiles through an impact on texture, aroma, and color (120). Indeed, sweetness and its role on palatability may be as much a function of other flavor-active compounds as of the sweetener itself (121).

The importance of sweetness liking on food choice also varies by food category (79, 81, 122). It may be more strongly associated with candy and snack intake than with sweet drink consumption, cereal/dairy/fruit products consumption, or added sugar consumption (122). This may reflect the variability in the primary motivation for ingesting different types of products, with sweetness playing a larger role for confections and snacks. Exposure frequency effects are also time-dependent, with recent exposure generally reducing the appeal of a sweet item (112).

## Extremes of Hedonics

### Cravings

Although there is currently no accepted definition of a craving, it is thought to be a special and intense case of liking that periodically motivates behavior toward obtaining the craved substance (123). In those that experience cravings, >50% of craved foods are predominantly sweet (117). There are several factors that influence sweet cravings (105, 124–131).

One of the greatest influencers of cravings is gender. Nearly all females state that they have experienced cravings, whereas only two-thirds to three-quarters of males state the same (105, 124, 125). Males are more likely to crave savory than sweet foods, whereas females are the opposite (105). Chocolate, traditionally viewed as sweet, is one of the most craved foods, especially among women in America (123, 124, 132). Forty-eight percent of females identify chocolate as their most intensely craved food, compared with only 18% of males (126). Culture may help explain this discrepancy, because data from other countries reveal no difference in chocolate cravings between men and women (105, 126). Another potential reason for these differences in cravings is that over half of females report cravings to be related to their menstrual cycle (123). In particular, females exhibit greater cravings for chocolate foods immediately before and during menses, although the exact mechanism underlying such cravings is currently unknown (133, 134). In addition, pregnant women are known to experience increased cravings (especially for sweet foods) (135).

Age (125) and alertness (127, 128) are positively associated with cravings, especially for energy-dense sweet foods. Although food cravings were previously theorized to be a result of a deficiency of energy or nutrients (136), a recent meta-analysis found that energy restriction is actually associated with reduced overall and sweet cravings (137). This is possibly due to energy restriction disrupting the association between a stimulus, environment, or occasion and the craving (137). That is, cravings can be specific to a time, place, and set of conditions. It is undetermined if there is a specific diet that works best to limit flavor cravings. Low-carbohydrate diets have been associated with both reduced (130, 138, 139) and increased (131) sweet cravings compared with habitual diets. A role of genetics is uncertain. One study reported those with $\geq 1$ A allele of the fat mass and obesity associated gene (*FTO*) rs9939609 experienced greater food cravings than the TT homozygotes (129), whereas this was not observed in another study (140).

There is considerable debate as to whether an addiction can develop to sweetness. Evidence from animal studies suggests exposure to sugars can evoke neurochemical and behavioral responses similar to those observed with administration of drugs of abuse (141). However, these responses are more closely linked to palatability than a specific sweetener (including LCSs) (142). The evidence from human trials is less compelling (143, 144). Again, there is a lack of evidence implicating any specific sweetener and assessment of "food addiction" reveals a lack of association with sugar or carbohydrate intake (145).

### Aversions

A food aversion is avoidance of a food after its ingestion has been temporally paired with illness (most commonly nausea or vomiting). Over one-third of the general population has formed a food aversion at some point in their life, whereas about one-quarter of the population currently has an aversion (146). However, sweet foods are not a common target of food aversions. In a study of aversive foods, only 18% of aversions involved sweet foods (117), a prevalence that is notably low given the high frequency of exposure to sweet foods. Aversions toward high-protein and high-fat foods are much more common (146, 147). This may be because protein and fat stimulate gastric acid secretion and an increased likelihood of gastric reflux, which may augment any other sensations of malaise (146). In addition, prior dislike of a food is known to facilitate both the acquisition and persistence of aversions, and sweet foods are generally well liked (148).

### Monotony

Monotony stems from increased exposure to a food or foods with a common characteristic and may result in reduced appeal and intake of that food (149). The teleological explanation for monotony is that it promotes a greater variety in food choice, thereby increasing the probability of ingesting all needed nutrients and reducing nutrient imbalances and exposure to high amounts of toxins (150).

The role of sweetness in monotony is unclear. Some evidence suggests sweet foods are relatively resistant to monotony effects (151, 152). However, the opposite has also been noted because sweet items with high initial pleasantness ratings (e.g., chocolate) may show greater reductions of both pleasantness and desire to eat over time (153, 154). The reason for this discrepancy may be related to consumption frequency. Selected highly liked foods, such as cakes and cookies, have a much lower desired consumption frequency than staple foods, such as bread and milk. Therefore, consumers may experience monotony for sweet foods much more quickly if they are instructed to eat these foods at a greater frequency than would be their habit (155).

### Neophobia

Neophobia, the fear of novel foods, may have had survival value as a protection from food toxins for our human ancestors (156). However, neophobia is now relied upon less and may hold negative consequences for children's diet quality (156–158). Neophobia can be overcome by repeated exposure to an item such that preference for the once-feared food increases after it is tasted many times (159). Novel sweet (and salty) foods quickly overcome neophobia, as shown by consistent, rapid increases in pleasantness ratings with repeated exposure, whereas bitter and sour foods are more resistant to exposure effects (160). The reason for this is likely due to the fact that humans demonstrate innate preferences for sweet and salty tastes (161).

## Select Influential Factors of Sweet Hedonics

### Sex

Whereas some studies report men prefer higher concentrations of sucrose (162, 163) and give higher liking ratings of sweetness (164) than women, others find no differences in preference or liking ratings of sweetness between genders (165–167) and no differences between genders in sweet liking phenotypes (168, 169). Women's sweet preferences vary across the menstrual cycle; however, at which phase they are highest is inconsistent (170–174).

### Age

There is a heightened preference for sweetness during childhood and early adolescence that decreases during young adulthood (175–178). Preference for sweetness may be heightened again in older age, because elderly adults preferred higher concentrations of sweetness than young adults (162, 179, 180). Why children and adolescents have a higher sweetness preference than adults is unknown. The effect of age on sweetness preferences is also seen in rats (181). A teleological argument holds that it is due to the energy requirement for physical growth in childhood (118, 176–178, 182). Evidence for this is weak and mixed (183–185) and, contrary to the hypothesis, some data show children have a lower preference for high-fat foods than adults (186). Heightened sweet preferences during childhood and early adolescence are also not related to sweet taste sensitivity (187), nor does a loss in taste sensitivity necessarily explain an increase for sweet preferences in the elderly (162).

### Ethnicity and culture

The diverse cuisines around the world highlight the variety of preferred flavor principles of cultural groups (105) and how inherent predilections to favor (sweetness) or reject (bitterness) certain qualities can be overridden (188). That is, through personal experience and cultural influences, one learns where sweetness is appropriate, at what magnitude, and at what frequency. For instance, non-Hispanic black adults consume more added sugar than non-Hispanic white and Mexican-American adults (40), and black adults prefer higher concentrations of sweetness than whites (188) in America. In addition, westernized cultures (Americans, Europeans, Australians) prefer greater sweetness concentrations than do Asian cultures, with further differences between Asian cultures where South Asian cultures (Malaysian, Indian) have greater sweet preferences than Central Asian cultures (Chinese, Japanese, Korean) (189). This is in line with the recent DGA report that non-Hispanic Asians consume less sugar than do other racial and ethnic groups (9).

### Genetics

Variations in the sweet taste receptor gene alter sweet taste sensitivity. However, few studies have documented gene variation effects on hedonics. Single-nucleotide polymorphisms located upstream of the *TAS1R3* coding sequence strongly correlate with sweet taste thresholds and explain 16% of a population's variation in sweet sensitivity (190). Those with the CC allele have the ability to detect low concentrations of sucrose, whereas those with CT and TT alleles have lesser abilities to detect low concentrations of sucrose. Mothers who have TT alleles on the *TAS1R3* sweet receptor gene rs35744813 variant prefer water with a higher concentration of sucrose than those with CC alleles (177, 186). This was not observed in children (177, 186). Other studies have assessed the relations of bitter receptor genotype and 6-n-propylthiouracil (PROP) taster status with sweet liking, but results are mixed (164, 188, 191, 192). It should also be noted that genetically based individual differences in sensitivity to other taste qualities, especially bitterness, can influence sweet exposure because a number of LCSs also activate bitter receptors (193). Thus, susceptibility to sweetness sensitivity determined by the *TAS1R3* gene may influence sweetness preferences, but this requires further study.

## Approaches to Modify Sweet Hedonics

Recommendations to moderate intake of added sugars to reduce energy intake and risk of chronic disease are widespread. However, reducing added sugars may reduce diet sweetness and palatability, resulting in poor acceptance. Replacing sources of added sugars with LCSs may reduce energy intake while maintaining palatability; however, with limited guidance on LCS consumption from health agencies and continued excess added sugar intake with LCSs widely available, more strategies are warranted. As opposed to maintaining palatability by replacing added sugar with LCSs, several approaches to modify the hedonic response to sweetness have been proposed to aid reduction of dietary sugar and energy intake.

### Retrained palate

One approach to reduce added sugar intake is to reduce the preferred sweetness level of foods through a gradual reduction in oral exposure to sweetness. It is hypothesized that a gradual reduction of exposure will lead to a lower preferred sweetness level of foods (a hedonic shift) over time while maintaining palatability. This phenomenon has been observed with salt and fat reduction. In adults who adhered to a reduced-fat or -sodium diet for 12 wk, there was a downward hedonic shift such that pleasantness ratings for high-fat foods declined (114), the preferred fat content of foods declined (114), pleasantness ratings for lower concentrations of sodium increased (194), the acceptance of reduced-sodium foods increased (195), and there was lower sodium intake (195). The hedonic shift occurred and was reinforced by reduced oral sensory exposure to the taste quality rather than altered intake and/or metabolism of fat or salt. This interpretation is supported by the findings that those who reduced sensory exposure to salt or fat, with no change in total intake, experienced the hedonic shift, whereas those that reduced intake but maintained oral exposure did not experience a hedonic shift (114). The shift required ∼8–12 wk to occur. However, in contrast to this literature, a randomized controlled trial that tested this phenomenon with sugar found that a low-sweetness diet increased perceived sweet taste intensity, but differed from the studies with salt and fat in that it had no effect on rated pleasantness or preferred sweetness level in food and beverage samples (196). Whether the increased sweet taste intensity was due to reduced oral sensory exposure specifically was not tested. This change in sweetness intensity in the absence of a change in hedonics would likely not yield changes in dietary intake (80). Whether sweetness differs from tastes of salts and fats in susceptibility to exposure effects on hedonics is not known. Several clinical trials further exploring a hedonic shift in sweetness are underway.

A recent systematic review reported inconsistent evidence for the role of sweetness manipulation on generalized acceptance, preference, choice, and intake of sweet foods in the diet (112). This analysis indicated that in acute randomized controlled trials, higher sweetness exposure tended to reduce preference for sweetness, indicative of sensory-specific satiety. However, population cohort studies and longer-term randomized controlled trials reported equivocal evidence for sweetness exposure and sweetness hedonics and intake. Studies included in the review often only manipulated certain sweet foods or beverages within a diet without controlling sweetness of the entire diet. Future studies controlling for sweetness of the entire diet with no or minimal sweetness exposure compared with higher or present-day average sweetness exposure will better address whether retraining the palate through decreasing sensory exposure to sweetness in the entire diet is effective for reducing preference and liking of sweetness and reducing sugar intake. There is widespread recognition that reduced exposure to a single food can lead to altered preference for that food [e.g., low- compared with high-fat milk (197)]. Whether this would hold for sweet foods and whether targeting the primary sources of sugar intake would be a beneficial strategy for moderating sugar intake have not been tested.

### Neonatal programming

Exposure to flavors from the mother's diet in amniotic fluid and breast milk can lead to acceptance of those flavors later in life (106, 107). This has been associated with short-term increased fruit and vegetable consumption. However, whether the mother's diet influences an infant's liking and preference for sweetness in general has not been measured.

Although not an approach to purposefully modify sweet hedonics, there is suggestive evidence of neonatal programming of food choice in those who were born preterm or were intrauterine growth restricted (IUGR). Adults who were IUGR or preterm have lower intake of fruits and vegetables (198) and increased energy and carbohydrate intake (199) compared with those who were born at term and are normal-weight. Studies also report that IUGR and preterm infants have a lower hedonic response to a sucrose solution than term and normal-weight infants. However, this was not the primary outcome of the work (200). Thus, sweet hedonics may be modified by IUGR or birth weight, but research specifically addressing this question is needed.

## Conclusions

Humans are drawn to sweetness. Although sensitivity and intensity may play a role, the primary driver of consumption of sweet foods and beverages is their sensory appeal. To quantify sensory hedonics, multiple approaches are required including assessments of liking, preference, and consumption intent. There is an innate desire for sweetness but this is modified by dietary experience, culture, and biology. People learn where sweetness is appropriate and at what level of intensity as well as when such foods can/should be ingested. In the United States, the prevailing forces result in high amounts of sweet exposure through increasing use of LCS-containing products and intake of added sugars (currently 12.7% of daily energy). Although there has been some reduction of sugar intake over the past 2 decades, most recommendations are to reduce this further (e.g., <10% of daily energy according to the 2020–2025 DGA). Several strategies have been proposed to moderate the appeal of sweetness or replace nutritive sweeteners with LCSs to facilitate this change, but the efficacy of such approaches remains to be determined.

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## References


1. Eertmans A, Baeyens F, Van den Bergh O. Food likes and their relative importance in human eating behavior: review and preliminary suggestions for health promotion. Health Educ Res 2001;16(4):443–56.
2. International Food Information Council (IFIC). 2020 Food & Health Survey. Washington (DC): IFIC; 2020.
3. Aggarwal A, Rehm CD, Monsivais P, Drewnowski A. Importance of taste, nutrition, cost and convenience in relation to diet quality: evidence of nutrition resilience among US adults using National Health and Nutrition Examination Survey (NHANES) 2007–2010. Prev Med 2016;90:184–92.
4. Stanton J. Taste remains consumers' top preference for new foods and beverages [Internet]. Schaumburg, IL: Food Processing; 2013 [cited 28 September, 2020]. Available from: https://www.foodprocessing.com/articles/2013/market-view-taste/.
5. Driggs J, Levin L. Product innovation and the pace of change. Chicago, IL: IRi; 2019.
6. Sloan E. Top 10 functional food trends [Internet]. Chicago, IL: Institute of Food Technologists; 2018 [cited 28 September, 2020]. Available from: https://www.ift.org/news-and-publications/food-technology-magazine/issues/2018/april/features/top-10-functional-food-trends-2018.
7. USDA Economic Research Service (ERS). Americans' budget share for total food was at a historical low of 9.5 percent in 2019 [Internet]. Washington (DC): USDA ERS; 2020 [cited 28 September, 2020]. Available from: https://www.ers.usda.gov/data-products/chart-gallery/gallery/chart-detail/?chartId=76967.
8. Sylvetsky AC, Rother KI. Trends in the consumption of low-calorie sweeteners. Physiol Behav 2016;164(Pt B):446–50.
9. Dietary Guidelines Advisory Committee. Scientific Report of the 2020 Dietary Guidelines Advisory Committee: advisory report to the Secretary of Agriculture and the Secretary of Health and Human Services. Washington (DC): USDA Agricultural Research Service; 2020.
10. Mattes R. Effects of aspartame and sucrose on hunger and energy intake in humans. Physiol Behav 1990;47(6):1037–44.
11. Drewnowski A, Massien C, Louis-Sylvestre J, Fricker J, Chapelot D, Apfelbaum M. Comparing the effects of aspartame and sucrose on motivational ratings, taste preferences, and energy intakes in humans. Am J Clin Nutr 1994;59(2):338–45.
12. Little TJ, Gupta N, Case RM, Thompson DG, McLaughlin JT. Sweetness and bitterness taste of meals per se does not mediate gastric emptying in humans. Am J Physiol Regul Integr Comp Physiol 2009;297(3):R632–9.
13. Teff KL, Devine J, Engelman K. Sweet taste: effect on cephalic phase insulin release in men. Physiol Behav 1995;57(6):1089–95.
14. McCrory MA, Burke A, Roberts SB. Dietary (sensory) variety and energy balance. Physiol Behav 2012;107(4):576–83.
15. Johnson F, Wardle J. Variety, palatability, and obesity. Adv Nutr 2014;5(6):851–9.
16. Blundell JE, Rogers PJ, Hill A. Uncoupling sweetness and calories: methodological aspects of laboratory studies on appetite control. Appetite 1988;11:54–61.
17. Tordoff MG, Alleva AM. Oral stimulation with aspartame increases hunger. Physiol Behav 1990;47(3):555–9.
18. Tester J. Sweet taste sensation and postprandial gastrointestinal effects. Aust J Herbal Med 2017;29(2):71–2.
19. Just T, Pau HW, Engel U, Hummel T. Cephalic phase insulin release in healthy humans after taste stimulation? Appetite 2008;51(3):622–7.
20. Dušková M, Macourek M, Šrámková M, Hill M, Stárka L. The role of taste in cephalic phase of insulin secretion. Prague Med Rep 2013;114(4):222–30.
21. Beauchamp GK, Cowart BJ. Development of sweet taste. In: Dobbing J, editor. Sweetness. London: Springer; 1987. p. 127–40.
22. Malik VS, Schulze MB, Hu FB. Intake of sugar-sweetened beverages and weight gain: a systematic review. Am J Clin Nutr 2006;84(2):274–88.
23. Hwang L-D, Cuellar-Partida G, Ong J-S, Breslin PA, Reed DR, MacGregor S, Gharahkhani P, Martin NG, Rentería ME. Sweet taste perception is associated with body mass index at the phenotypic and genotypic level. Twin Res Hum Genet 2016;19(5):465–71.
24. Te Morenga L, Mallard S, Mann J. Dietary sugars and body weight: systematic review and meta-analyses of randomised controlled trials and cohort studies. BMJ 2013;346:e7492.
25. Peters JC, Beck J. Low calorie sweetener (LCS) use and energy balance. Physiol Behav 2016;164:524–8.
26. Miller PE, Perez V. Low-calorie sweeteners and body weight and composition: a meta-analysis of randomized controlled trials and prospective cohort studies. Am J Clin Nutr 2014;100(3):765–77.
27. Rogers P, Hogenkamp P, De Graaf C, Higgs S, Lluch A, Ness A, Penfold C, Perry R, Putz P, Yeomans M. Does low-energy sweetener consumption affect energy intake and body weight? A systematic review, including meta-analyses, of the evidence from human and animal studies. Int J Obes 2016;40(3):381–94.
28. Gibson SA, Horgan GW, Francis LE, Gibson AA, Stephen AM. Low calorie beverage consumption is associated with energy and nutrient intakes and diet quality in British adults. Nutrients 2016;8(1):9.
29. Drewnowski A, Rehm CD. Consumption of low-calorie sweeteners among US adults is associated with higher healthy eating index (HEI 2005) scores and more physical activity. Nutrients 2014;6(10):4389–403.
30. Sylvetsky AC, Figueroa J, Zimmerman T, Swithers SE, Welsh JA. Consumption of low-calorie sweetened beverages is associated with higher total energy and sugar intake among children, NHANES 2011–2016. Pediatr Obes 2019;14(10):e12535.
31. Trumbo PR, Appleton KM, de Graaf K, Hayes JE, Baer DJ, Beauchamp GK, Dwyer JT, Fernstrom JD, Klurfeld DM, Mattes RD, et al. Perspective: measuring sweetness in foods, beverages, and diets: toward understanding the role of sweetness in health. Adv Nutr 2021;12(2):343–54.
32. Zhu Y, Hollis JH. Associations between eating frequency and energy intake, energy density, diet quality and body weight status in adults from the USA. Br J Nutr 2016;115(12):2138–44.
33. WHO. Reducing free sugars intake in children and adults [Internet]. Geneva, Switzerland: WHO; 2021[cited 31 January, 2021]. Available from: http://www.who.int/elena/titles/guidance_summaries/sugars_intake/en/.
34. Gwak M-J, Chung S-J, Kim YJ, Lim CS. Relative sweetness and sensory characteristics of bulk and intense sweeteners. Food Sci Biotechnol 2012;21(3):889–94.
35. Moraru C. Formulating in sweetness. Skokie, IL: Prepared Foods; 2011.
36. Powell ES, Smith-Taillie LP, Popkin BM. Added sugars intake across the distribution of US children and adult consumers: 1977-2012. J Acad Nutr Diet 2016;116(10):1543–50.e1.
37. Popkin BM, Nielsen SJ. The sweetening of the world's diet. Obes Res 2003;11(11):1325–32.
38. Welsh JA, Sharma AJ, Grellinger L, Vos MB. Consumption of added sugars is decreasing in the United States. Am J Clin Nutr 2011;94(3):726–34.
39. Ervin RB, Kit BK, Carroll MD, Ogden C. Consumption of added sugar among US children and adolescents, 2005–2008. NCHS Data Brief 2012;(87):1–8.
40. Ervin RB, Ogden CL. Consumption of added sugars among U.S. adults, 2005–2010. NCHS Data Brief 2013;(122):1–8.
41. Han E, Powell LM. Consumption patterns of sugar-sweetened beverages in the United States. J Acad Nutr Diet 2013;113(1):43–53.
42. Kit BK, Fakhouri THI, Park S, Nielsen SJ, Ogden CL. Trends in sugar-sweetened beverage consumption among youth and adults in the United States: 1999–2010. Am J Clin Nutr 2013;98(1):180–8.

43. Rosinger A, Herrick K, Gahche J, Park S. Sugar-sweetened beverage consumption among U.S. youth, 2011–2014. NCHS Data Brief 2017;(271):1–8.
44. Rosinger A, Herrick K, Gahche J, Park S. Sugar-sweetened beverage consumption among U.S. adults, 2011–2014. NCHS Data Brief 2017;(270):1–8.
45. Popkin BM, Hawkes C. The sweetening of the global diet, particularly beverages: patterns, trends, and policy responses for diabetes prevention. Lancet Diabetes Endocrinol 2016;4(2):174–86.
46. Block G. Foods contributing to energy intake in the US: data from NHANES III and NHANES 1999–2000. J Food Compos Anal 2004;17(3–4):439–47.
47. Sylvetsky AC, Welsh JA, Brown RJ, Vos MB. Low-calorie sweetener consumption is increasing in the United States. Am J Clin Nutr 2012;96(3):640–6.
48. Piernas C, Ng SW, Popkin B. Trends in purchases and intake of foods and beverages containing caloric and low-calorie sweeteners over the last decade in the United States. Pediatr Obes 2013;8(4):294–306.
49. Slining MM, Ng SW, Popkin BM. Food companies' calorie-reduction pledges to improve US diet. Am J Prev Med 2013;44(2):174–84.
50. Mattes RD, Popkin BM. Nonnutritive sweetener consumption in humans: effects on appetite and food intake and their putative mechanisms. Am J Clin Nutr 2009;89(1):1–14.
51. Fakhouri THI, Kit BK, Ogden CL. Consumption of diet drinks in the United States, 2009–2010. NCHS Data Brief 2012;(109):1–8.
52. Dietary Guidelines Advisory Committee. Scientific Report of the 2015 Dietary Guidelines Advisory Committee: advisory report to the Secretary of Agriculture and the Secretary of Health and Human Services. Washington (DC): USDA Agricultural Research Service; 2015.
53. Mollard RC, Wong CL, Luhovyy BL, Anderson GH. First and second meal effects of pulses on blood glucose, appetite, and food intake at a later meal. Appl Physiol Nutr Metab 2011;36(5):634–42.
54. Bowman SA, Clemens JC, Friday JE, LaComb RP, Paudel D, Shimizu M. Added sugars in adults' diet: What We Eat in America, NHANES 2015-2016. Dietary Data Brief No. 24. Beltsville, MD: USDA Agricultural Research Service, Food Surveys Research Group; 2019.
55. Bowman S, Clemens J, Friday J, Schroeder N, LaComb R. Added sugars in American children's diet: What We Eat in America, NHANES 2015-2016. Dietary Data Brief No. 26. Beltsville, MD: USDA Agricultural Research Service, Food Surveys Research Group; 2019.
56. Louie JCY, Tapsell LC. Association between intake of total vs added sugar on diet quality: a systematic review. Nutr Rev 2015;73(12):837–57.
57. WHO. Guideline: sugars intake for adults and children. Geneva, Switzerland: World Health Organization; 2015.
58. Diabetes Canada. Sugar & diabetes: position statement [Internet]. Toronto, Ontario: Canadian Diabetes Association; 2020 [cited 28 September, 2020]. Available from: https://www.diabetes.ca/advocacy---policies/our-policy-positions/sugar---diabetes.
59. Scientific Advisory Committee on Nutrition. Carbohydrates and health. London: The Stationery Office; 2015.
60. Healthy People 2020. Food and nutrient consumption: NWS-17.2 Reduce consumption of calories from added sugars[Internet]. Washington (DC): US Department of Health and Human Services; 2014 [cited 28 September 2020]. Available from: https://www.healthypeople.gov/2020/topics-objectives/objective/nws-172.
61. Johnson RK, Appel LJ, Brands M, Howard BV, Lefevre M, Lustig RH, Sacks F, Steffen LM, Wylie-Rosett J. Dietary sugars intake and cardiovascular health: a scientific statement from the American Heart Association. Circulation 2009;120(11):1011–20.
62. Institute of Medicine Food and Nutrition Board. Dietary carbohydrates: sugars and starches. In: Dietary Reference Intakes for energy, carbohydrate, fiber, fat, fatty acids, cholesterol, protein, and amino acids. Washington (DC): The National Academies Press; 2005. p. 265–338.
63. Clemens R, Papanikolaou Y. Crystalizing global sugar policy: public health promise or perception. In: Rippe JM, editor. Fructose, high fructose corn syrup, sucrose and health. New York, NY: Springer; 2014. p. 125–35.
64. Wescott RF, Fitzpatrick BM, Phillips E. Industry self-regulation to improve student health: quantifying changes in beverage shipments to schools. Am J Public Health 2012;102(10): 1928–35.
65. Jebb SA. Carbohydrates and obesity: from evidence to policy in the UK. Proc Nutr Soc 2015;74(3):215–20.
66. Hsiao A, Wang YC. Reducing sugar-sweetened beverage consumption: evidence, policies, and economics. Curr Obes Rep 2013;2(3): 191–9.
67. The Food Industry Association (FMI). U.S. grocery shopper trends. Arlington, VA: FMI; 2019.
68. Gardner C, Wylie-Rosett J, Gidding SS, Steffen LM. Nonnutritive sweeteners: current use and health perspectives: a scientific statement from the American Heart Association and the American Diabetes Association. Circulation 2012;126(4):509–19.
69. Johnson RK, Lichtenstein AH, Anderson CAM, Carson JA, Despres J-P, Hu FB, Kris-Etherton PM, Otten JJ, Towfighi A, Wylie-Rosett J, et al. Low-calorie sweetened beverages and cardiometabolic health: a science advisory from the American Heart Association. Circulation 2018;138(9):e126–e40.
70. Tedstone A, Targett V, Allen R. Sugar reduction: the evidence for action. London: Public Health England; 2015.
71. Health Canada. Canada's Food Guide: sugar substitutes and healthy eating [Internet]. Ottawa, Ontario: Health Canada; 2019 [cited 28 September 2020]. Available from: https://food-guide.canada.ca/en/tips-for-healthy-eating/sugar-substitutes-and-healthy-eating/.
72. Rogers PJ. The role of low-calorie sweeteners in the prevention and management of overweight and obesity: evidence *v.* conjecture. Proc Nutr Soc 2018;77(3):230–8.
73. Hunter SR, Reister EJ, Cheon E, Mattes RD. Low calorie sweeteners differ in their physiological effects in humans. Nutrients 2019;11(11):2717.
74. Mattes RD. Gustation as a determinant of ingestion: methodological issues. Am J Clin Nutr 1985;41(4):672–83.
75. Mattes RM. Gustation and nutrition. Chem Senses 1985;10:456–7.
76. Mattes RD, Mela DJ. Relationships between and among selected measures of sweet-taste preference and dietary intake. Chem Senses 1986;11(4):523–39.
77. Holt S, Cobiac L, Beaumont-Smith N, Easton K, Best D. Dietary habits and the perception and liking of sweetness among Australian and Malaysian students: a cross-cultural study. Food Qual Prefer 2000;11(4):299–312.
78. Cicerale S, Riddell LJ, Keast RS. The association between perceived sweetness intensity and dietary intake in young adults. J Food Sci 2012;77(1):H31–5.
79. Jayasinghe SN, Kruger R, Walsh DC, Cao G, Rivers S, Richter M, Breier BH. Is sweet taste perception associated with sweet food liking and intake? Nutrients 2017;9(7):750.
80. Tan S-Y, Tucker RM. Sweet taste as a predictor of dietary intake: a systematic review. Nutrients 2019;11(1):94.
81. Mahar A, Duizer LM. The effect of frequency of consumption of artificial sweeteners on sweetness liking by women. J Food Sci 2007;72(9):S714–18.
82. Wise PM, Breslin PAS. Individual differences in sour and salt sensitivity: detection and quality recognition thresholds for citric acid and sodium chloride. Chem Senses 2013;38(4):333–42.
83. Monsen ER, Van Horn L. Research: successful approaches. Chicago, IL: American Dietetic Association; 2007.
84. Moskowitz HR. Ratio scales of sugar sweetness. Percept Psychophys 1970;7(5):315–20.
85. Giovanni ME, Pangborn RM. Measurement of taste intensity and degree of liking of beverages by graphic scales and magnitude estimation. J Food Sci 1983;48(4):1175–82.
86. Miller GA. The magical number seven, plus or minus two: some limits on our capacity for processing information. Psychol Rev 1956;63(2):81–97.

87. Green BG, Shaffer GS, Gilmore MM. Derivation and evaluation of a semantic scale of oral sensation magnitude with apparent ratio properties. Chem Senses 1993;18(6):683–702.
88. Green BG, Dalton P, Cowart B, Shaffer G, Rankin K, Higgins J. Evaluating the 'Labeled Magnitude Scale' for measuring sensations of taste and smell. Chem Senses 1996;21(3):323–34.
89. Hayes J. Measuring sensory perception in relation to consumer behavior. In: Delarue J, Lawlor B, editors. Rapid sensory profiling techniques. Sawston, UK: Woodhead Publishing; 2015. p. 53–69.
90. Bower JA, Saadat MA, Whitten C. Effect of liking, information and consumer characteristics on purchase intention and willingness to pay more for a fat spread with a proven health benefit. Food Qual Prefer 2003;14(1):65–74.
91. Birch LL. Preschool children's food preferences and consumption patterns. J Nutr Educ 1979;11(4):189–92.
92. Caporale G, Policastro S, Tuorila H, Monteleone E. Hedonic ratings and consumption of school lunch among preschool children. Food Qual Prefer 2009;20(7):482–9.
93. Zandstra EH, De Graaf C, Mela DJ, Van Staveren WA. Short- and long-term effects of changes in pleasantness on food intake. Appetite 2000;34(3):253–60.
94. Vickers Z, Holton E, Wang J. Effect of ideal–relative sweetness on yogurt consumption. Food Qual Prefer 2001;12(8):521–6.
95. Randall E, Sanjur D. Food preferences—their conceptualization and relationship to consumption. Ecol Food Nutr 1981;11(3):151–61.
96. Duffy VB, Hayes JE, Sullivan BS, Faghri P. Surveying food and beverage liking: a tool for epidemiological studies to connect chemosensation with health outcomes. Ann N Y Acad Sci 2009;1170(1):558–68.
97. Lapis TJ, Penner MH, Lim J. Evidence that humans can taste glucose polymers. Chem Senses 2014;39(9):737–47.
98. Lim J, Pullicin AJ. Oral carbohydrate sensing: beyond sweet taste. Physiol Behav 2019;202:14–25.
99. Mattes RD. Taste, teleology and macronutrient intake. Curr Opin Physiol 2021;19:162–7.
100. de Snoo K. Das trinkende Kind im Uterus. Gynecol Obstet Invest 1937;105(2–3):88–97.
101. Ganchrow JR, Steiner JE, Daher M. Neonatal facial expressions in response to different qualities and intensities of gustatory stimuli. Infant Behav Dev 1983;6(4):473–84.
102. Liley AW. Disorders of amniotic fluid. In: Assali NS, editor. Fetal-placental disorders. New York: Academic Press; 1972. p. 157–206.
103. Maone TR, Mattes RD, Bernbaum JC, Beauchamp GK. A new method for delivering a taste without fluids to preterm and term infants. Dev Psychobiol 1990;23(2):179–91.
104. Bufe B, Breslin PAS, Kuhn C, Reed DR, Tharp CD, Slack JP, Kim U-K, Drayna D, Meyerhof W. The molecular basis of individual differences in phenylthiocarbamide and propylthiouracil bitterness perception. Curr Biol 2005;15(4):322–7.
105. Zellner DA, Garriga-Trillo A, Rohm E, Centeno S, Parker S. Food liking and craving: a cross-cultural approach. Appetite 1999;33(1):61–70.
106. Mennella JA, Jagnow CP, Beauchamp GK. Prenatal and postnatal flavor learning by human infants. Pediatrics 2001;107(6):e88.
107. Mennella JA, Johnson A, Beauchamp GK. Garlic ingestion by pregnant women alters the odor of amniotic fluid. Chem Senses 1995;20(2):207–9.
108. Ventura AK, Mennella JA. Innate and learned preferences for sweet taste during childhood. Curr Opin Clin Nutr Metab Care 2011;14(4):379–84.
109. Liem DG, Mennella JA. Sweet and sour preferences during childhood: role of early experiences. Dev Psychobiol 2002;41(4):388–95.
110. Beauchamp GK, Moran M. Acceptance of sweet and salty tastes in 2-year-old children. Appetite 1984;5(4):291–305.
111. Liem DG, de Graaf C. Sweet and sour preferences in young children and adults: role of repeated exposure. Physiol Behav 2004;83(3):421–9.
112. Appleton KM, Tuorila H, Bertenshaw EJ, de Graaf C, Mela DJ. Sweet taste exposure and the subsequent acceptance and preference for sweet taste in the diet: systematic review of the published literature. Am J Clin Nutr 2018;107(3):405–19.
113. Bertino M, Beauchamp GK, Engelman K. Long-term reduction in dietary sodium alters the taste of salt. Am J Clin Nutr 1982;36(6):1134–44.
114. Mattes RD. Fat preference and adherence to a reduced-fat diet. Am J Clin Nutr 1993;57(3):373–81.
115. Steiner JE. Human facial expressions in response to taste and smell stimulation. In: Reese HW, Lipsitt LP, editors. Advances in child development and behavior. Atlanta, GA: JAI; 1979. p. 257–95.
116. Bergamasco NH, Beraldo KE. Facial expressions of neonate infants in response to gustatory stimuli. Braz J Med Biol Res 1990;23(3–4):245–9.
117. Blank DM, Mattes RD. Exploration of the sensory characteristics of craved and aversive foods. J Sens Stud 1990;5(3):193–202.
118. Reed DR, McDaniel AH. The human sweet tooth. BMC Oral Health 2006;6(S1):S17.
119. Cornelis MC, Tordoff MG, El-Sohemy A, van Dam RM. Recalled taste intensity, liking and habitual intake of commonly consumed foods. Appetite 2017;109:182–9.
120. Quitral V, Valdés J, Umaña V, Gallardo N, Alcaino MJ, Araya C, Flores M. The role of non-caloric sweeteners in sensory characteristics of pastry products. Foods 2019;8(8):329.
121. Chadwick M, Gawthrop F, Michelmore RW, Wagstaff C, Methven L. Perception of bitterness, sweetness and liking of different genotypes of lettuce. Food Chem 2016;197:66–74.
122. Divert C, Chabanet C, Schoumacker R, Martin C, Lange C, Issanchou S, Nicklaus S. Relation between sweet food consumption and liking for sweet taste in French children. Food Qual Prefer 2017;56:18–27.
123. Rozin P, Levine E, Stoess C. Chocolate craving and liking. Appetite 1991;17(3):199–212.
124. Weingarten HP, Elston D. Food cravings in a college population. Appetite 1991;17(3):167–75.
125. Pelchat ML. Food cravings in young and elderly adults. Appetite 1997;28(2):103–13.
126. Osman JL, Sobal J. Chocolate cravings in American and Spanish individuals: biological and cultural influences. Appetite 2006;47(3):290–301.
127. Lv W, Finlayson G, Dando R. Sleep, food cravings and taste. Appetite 2018;125:210–16.
128. Spiegel K, Tasali E, Penev P, Van Cauter E. Brief communication: sleep curtailment in healthy young men is associated with decreased leptin levels, elevated ghrelin levels, and increased hunger and appetite. Ann Intern Med 2004;141(11):846–50.
129. Dang LC, Samanez-Larkin GR, Smith CT, Castrellon JJ, Perkins SF, Cowan RL, Claassen DO, Zald DH. FTO affects food cravings and interacts with age to influence age-related decline in food cravings. Physiol Behav 2018;192:188–93.
130. Anguah KO-B, Syed-Abdul MM, Hu Q, Jacome-Sosa M, Heimowitz C, Cox V, Parks EJ. Changes in food cravings and eating behavior after a dietary carbohydrate restriction intervention trial. Nutrients 2020;12(1):52.
131. Jakubowicz D, Froy O, Wainstein J, Boaz M. Meal timing and composition influence ghrelin levels, appetite scores and weight loss maintenance in overweight and obese adults. Steroids 2012;77(4):323–31.
132. Massey A, Hill AJ. Dieting and food craving. A descriptive, quasi-prospective study. Appetite 2012;58(3):781–5.
133. Tomelleri R, Grunewald KK. Menstrual cycle and food cravings in young college women. J Am Diet Assoc 1987;87(3):311–15.
134. Hormes JM, Timko CA. All cravings are not created equal. Correlates of menstrual versus non-cyclic chocolate craving. Appetite 2011;57(1):1–5.
135. Hook EB. Dietary cravings and aversions during pregnancy. Am J Clin Nutr 1978;31(8):1355–62.

136. Weingarten HP, Elston D. The phenomenology of food cravings. Appetite 1990;15(3):231–46.
137. Kahathuduwa CN, Binks M, Martin CK, Dawson JA. Extended calorie restriction suppresses overall and specific food cravings: a systematic review and a meta-analysis. Obes Rev 2017;18(10):1122–35.
138. Castro AI, Gomez-Arbelaez D, Crujeiras AB, Granero R, Aguera Z, Jimenez-Murcia S, Sajoux I, Lopez-Jaramillo P, Fernandez-Aranda F, Casanueva FF. Effect of a very low-calorie ketogenic diet on food and alcohol cravings, physical and sexual activity, sleep disturbances, and quality of life in obese patients. Nutrients 2018;10(10):1348.
139. Martin CK, Rosenbaum D, Han H, Geiselman PJ, Wyatt HR, Hill JO, Brill C, Bailer B, Miller-III BV, Stein R. Change in food cravings, food preferences, and appetite during a low-carbohydrate and low-fat diet. Obesity 2011;19(10):1963–70.
140. Abdella HM, El Farssi HO, Broom DR, Hadden DA, Dalton CF. Eating behaviours and food cravings; influence of age, sex, BMI and *FTO* genotype. Nutrients 2019;11(2):377.
141. DiNicolantonio JJ, O'Keefe JH, Wilson WL. Sugar addiction: is it real? A narrative review. Br J Sports Med 2018;52(14):910–13.
142. Tellez LA, Han W, Zhang X, Ferreira TL, Perez IO, Shammah-Lagnado SJ, van den Pol AN, de Araujo IE. Separate circuitries encode the hedonic and nutritional values of sugar. Nat Neurosci 2016;19(3):465–70.
143. Benton D. The plausibility of sugar addiction and its role in obesity and eating disorders. Clin Nutr 2010;29(3):288–303.
144. Westwater ML, Fletcher PC, Ziauddeen H. Sugar addiction: the state of the science. Eur J Nutr 2016;55(S2):55–69.
145. Pursey KM, Collins CE, Stanwell P, Burrows TL. Foods and dietary profiles associated with 'food addiction' in young adults. Addict Behav Rep 2015;2:41–8.
146. Mattes RD. Learned food aversions: a family study. Physiol Behav 1991;50(3):499–504.
147. Scott CL, Downey RG. Types of food aversions: animal, vegetable, and texture. J Psychol 2007;141(2):127–34.
148. Garb JL, Stunkard AJ. Taste aversions in man. Am J Psychiatry 1974;131(11):1204–7.
149. Raynor HA, Niemeier HM, Wing RR. Effect of limiting snack food variety on long-term sensory-specific satiety and monotony during obesity treatment. Eat Behav 2006;7(1):1–14.
150. Remick AK, Polivy J, Pliner P. Internal and external moderators of the effect of variety on food intake. Psychol Bull 2009;135(3): 434–51.
151. Schutz HG, Pilgrim FJ. A field study of food monotony. Psychol Rep 1958;4(3):559–65.
152. Weijzen PLG, Zandstra EH, Alfieri C, de Graaf C. Effects of complexity and intensity on sensory specific satiety and food acceptance after repeated consumption. Food Qual Prefer 2008;19(4): 349–59.
153. Hetherington MM, Bell A, Rolls BJ. Effects of repeat consumption on pleasantness, preference and intake. Br Food J 2000;102:507–21.
154. Hetherington MM, Pirie LM, Nabb S. Stimulus satiation: effects of repeated exposure to foods on pleasantness and intake. Appetite 2002;38(1):19–28.
155. Moskowitz HR. Psychometric evaluation of food preferences. Foodserv Res Int 1980;1(2):149–67.
156. Howard AJ, Mallan KM, Byrne R, Magarey A, Daniels LA. Toddlers' food preferences. The impact of novel food exposure, maternal preferences and food neophobia. Appetite 2012;59(3):818–25.
157. Cooke L, Carnell S, Wardle J. Food neophobia and mealtime food consumption in 4–5 year old children. Int J Behav Nutr Phys Act 2006;3(1):1–6.
158. Cooke L, Wardle J, Gibson EL. Relationship between parental report of food neophobia and everyday food consumption in 2–6-year-old children. Appetite 2003;41(2):205–6.
159. Pliner P, Pelchat M, Grabski M. Reduction of neophobia in humans by exposure to novel foods. Appetite 1993;20(2):111–23.
160. Mattes RD. Influences on acceptance of bitter foods and beverages. Physiol Behav 1994;56(6):1229–36.
161. Wardle J, Cooke L. Genetic and environmental determinants of children's food preferences. Br J Nutr 2008;99(S1):S15–21.
162. Mojet J, Christ-Hazelhof E, Heidema J. Taste perception with age: pleasantness and its relationships with threshold sensitivity and supra-threshold intensity of five taste qualities. Food Qual Prefer 2005;16(5):413–23.
163. Hayes JE, Duffy VB. Oral sensory phenotype identifies level of sugar and fat required for maximal liking. Physiol Behav 2008;95(1–2):77–87.
164. Yeomans MR, Tepper BJ, Rietzschel J, Prescott J. Human hedonic responses to sweetness: role of taste genetics and anatomy. Physiol Behav 2007;91(2–3):264–73.
165. Beauchamp GK, Moran M. Dietary experience and sweet taste preference in human infants. Appetite 1982;3(2):139–52.
166. Weafer J, Lyon N, Hedeker D, de Wit H. Sweet taste liking is associated with subjective response to amphetamine in women but not men. Psychopharmacology (Berl) 2017;234(21):3185–94.
167. Tremblay KA, Bona JM, Kranzler HR. Effects of a diagnosis or family history of alcoholism on the taste intensity and hedonic value of sucrose. Am J Addict 2009;18(6):494–9.
168. Iatridi V, Hayes JE, Yeomans MR. Quantifying sweet taste liker phenotypes: time for some consistency in the classification criteria. Nutrients 2019;11(1):129.
169. Asao K, Miller J, Arcori L, Lumeng JC, Han-Markey T, Herman WH. Patterns of sweet taste liking: a pilot study. Nutrients 2015;7(9):7298–311.
170. Bowen DJ, Grunberg NE. Variations in food preference and consumption across the menstrual cycle. Physiol Behav 1990;47(2):287–91.
171. Pliner P, Fleming AS. Food intake, body weight, and sweetness preferences over the menstrual cycle in humans. Physiol Behav 1983;30(4):663–6.
172. Frye CA, Crystal S, Ward KD, Kanarek RB. Menstrual cycle and dietary restraint influence taste preferences in young women. Physiol Behav 1994;55(3):561–7.
173. Wright P, Crow RA. Menstrual cycle: effect on sweetness preferences in women. Horm Behav 1973;4(4):387–91.
174. Elliott SA, Ng J, Leow MK-S, Henry CJK. The influence of the menstrual cycle on energy balance and taste preference in Asian Chinese women. Eur J Nutr 2015;54(8):1323–32.
175. De Graaf C, Zandstra EH. Sweetness intensity and pleasantness in children, adolescents, and adults. Physiol Behav 1999;67(4): 513–20.
176. Desor JA, Greene LS, Maller O. Preferences for sweet and salty in 9- to 15-year-old and adult humans. Science 1975;190(4215): 686–7.
177. Mennella JA, Finkbeiner S, Lipchock SV, Hwang LD, Reed DR. Preferences for salty and sweet tastes are elevated and related to each other during childhood. PLoS One 2014;9(3):e92201.
178. Desor JA, Beauchamp GK. Longitudinal changes in sweet preferences in humans. Physiol Behav 1987;39(5):639–41.
179. de Graaf C, Polet P, van Staveren WA. Sensory perception and pleasantness of food flavors in elderly subjects. J Gerontol 1994;49(3):P93–9.
180. Murphy C, Withee J. Age-related differences in the pleasantness of chemosensory stimuli. Psychol Aging 1986;1(4):312–18.
181. Bertino M, Wehmer F. Dietary influences on the development of sucrose acceptability in rats. Dev Psychobiol 1981;14(1):19–28.
182. Coldwell SE, Oswald TK, Reed DR. A marker of growth differs between adolescents with high vs. low sugar preference. Physiol Behav 2009;96(4–5):574–80.
183. Sobek G, Łuszczki E, Dąbrowski M, Dereń K, Baran J, Weres A, Mazur A. Preferences for sweet and fatty taste in children and their mothers in association with weight status. Int J Environ Res Public Health 2020;17(2):538.
184. Kern DL, McPhee L, Fisher J, Johnson S, Birch LL. The postingestive consequences of fat condition preferences for flavors associated with high dietary fat. Physiol Behav 1993;54(1):71–6.

185. Cox DN, van Galen M, Hedderley D, Perry L, Moore PB, Mela DJ. Sensory and hedonic judgments of common foods by lean consumers and consumers with obesity. Obes Res 1998;6(6):438–47.
186. Mennella JA, Finkbeiner S, Reed DR. The proof is in the pudding: children prefer lower fat but higher sugar than do mothers. Int J Obes 2012;36(10):1285–91.
187. Petty S, Salame C, Mennella JA, Pepino MY. Relationship between sucrose taste detection thresholds and preferences in children, adolescents, and adults. Nutrients 2020;12(7):1918.
188. Mennella JA, Pepino MY, Reed DR. Genetic and environmental determinants of bitter perception and sweet preferences. Pediatrics 2005;115(2):e216–22.
189. Venditti C, Musa-Veloso K, Lee HY, Poon T, Mak A, Darch M, Juana J, Fronda D, Noori D, Pateman E, et al. Determinants of sweetness preference: a scoping review of human studies. Nutrients 2020;12(3):718.
190. Fushan AA, Simons CT, Slack JP, Manichaikul A, Drayna D. Allelic polymorphism within the *TAS1R3* promoter is associated with human taste sensitivity to sucrose. Curr Biol 2009;19(15):1288–93.
191. Drewnowski A, Henderson SA, Shore AB, Barratt-Fornell A. Nontasters, tasters, and supertasters of 6-*n*-propylthiouracil (PROP) and hedonic response to sweet. Physiol Behav 1997;62(3): 649–55.
192. Drewnowski A, Henderson SA, Shore AB. Genetic sensitivity to 6-n-propylthiouracil (PROP) and hedonic responses to bitter and sweet tastes. Chem Senses 1997;22(1):27–37.
193. Kuhn C, Bufe B, Winnig M, Hofmann T, Frank O, Behrens M, Lewtschenko T, Slack JP, Ward CD, Meyerhof W. Bitter taste receptors for saccharin and acesulfame K. J Neurosci 2004;24(45):10260–5.
194. Beauchamp GK, Bertino M, Engelman K. Modification of salt taste. Ann Intern Med 1983;98(5_Part_2):763–9.
195. Institute of Medicine. Strategies to reduce sodium intake in the United States. Washington (DC): The National Academies Press; 2010.
196. Wise PM, Nattress L, Flammer LJ, Beauchamp GK. Reduced dietary intake of simple sugars alters perceived sweet taste intensity but not perceived pleasantness. Am J Clin Nutr 2016;103(1):50–60.
197. McCarthy K, Lopetcharat K, Drake M. Milk fat threshold determination and the effect of milk fat content on consumer preference for fluid milk. J Dairy Sci 2017;100(3):1702–11.
198. Kaseva N, Wehkalampi K, Hemiö K, Hovi P, Järvenpää AL, Andersson S, Eriksson JG, Lindström J, Kajantie E. Diet and nutrient intake in young adults born preterm at very low birth weight. J Pediatr 2013;163(1):43–8.
199. Barbieri MA, Portella AK, Silveira PP, Bettiol H, Agranonik M, Silva AA, Goldani MZ. Severe intrauterine growth restriction is associated with higher spontaneous carbohydrate intake in young women. Pediatr Res 2009;65(2):215–20.
200. Ayres C, Agranonik M, Portella AK, Filion F, Johnston CC, Silveira PP. Intrauterine growth restriction and the fetal programming of the hedonic response to sweet taste in newborn infants. Int J Pediatr 2012:657379.