Sweet taste exposure and the subsequent acceptance and preference for sweet taste in the diet: systematic review of the published literature

KM Appleton,[1] H Tuorila,[2] EJ Bertenshaw,[3] C de Graaf,[4] and DJ Mela[5]

[1]Department of Psychology, Faculty of Science and Technology, Bournemouth University, Bournemouth, United Kingdom; [2]Department of Food and Environmental Sciences, University of Helsinki, Helsinki, Finland; [3]Unilever R&D Colworth, Bedford, United Kingdom; [4]Division of Human Nutrition, Wageningen University, Wageningen, The Netherlands; and [5]Unilever R&D Vlaardingen, Vlaardingen, The Netherlands

ABSTRACT

Background: There are consistent, evidence-based global public health recommendations to reduce intakes of free sugars. However, the corresponding evidence for recommending reduced exposure to sweetness is less clear.

Objective: Our aim was to identify and review the published evidence investigating the impact of dietary exposure to sweet-tasting foods or beverages on the subsequent generalized acceptance, preference, or choice of sweet foods and beverages in the diet.

Design: Systematic searches were conducted to identify all studies testing relations of variation in exposure to sweetness through foods and beverages with subsequent variation in the generalized acceptance, preference, or choice of sweetened foods or beverages, in humans aged >6 mo.

Results: Twenty-one studies met our inclusion criteria, comprising 7 population cohort studies involving 2320 children and 14 controlled trials involving 1113 individuals. These studies were heterogeneous in study design, population, exposure, and outcomes measured, and few were explicitly designed to address our research question. The findings from these were inconsistent. We found equivocal evidence from population cohort studies. The evidence from controlled studies suggests that a higher sweet taste exposure tends to lead to reduced preferences for sweetness in the shorter term, but very limited effects were found in the longer term.

Conclusions: A small and heterogeneous body of research currently has considered the impact of varying exposure to sweet taste on subsequent generalized sweet taste preferences, and this evidence is equivocal regarding the presence and possible direction of a relation. Future work should focus on adequately powered studies with well-characterized exposures of sufficient duration. This review was registered with PROSPERO as CRD42016051840, 24 November 2016. *Am J Clin Nutr* 2018;107:405–419.

Keywords: sweet taste, exposure, food preferences, food choice, food intake

INTRODUCTION

There is a clear, evidence-based global public health mandate to limit the consumption of free sugars in the diet (1). However,

the question arises as to whether it is not only exposure to sugars that should be reduced but also exposure to sweet taste.

Sweet taste is innately rewarding, as characterized by a universal liking for high levels of sweetness in foods and beverages in infancy and childhood (2), and it is possible that high levels of sweetness or sustained exposures to sweet taste help maintain or even promote a generalized desire for sweet(er) foods and beverages in the wider diet. Such a generalized "sweet tooth" could make it challenging for individuals to reduce intakes of free sugars (3, 4).

Alternatively, it is possible to formulate foods and beverages that retain their sweetness at a substantially reduced free-sugar content. The exposure to sweetness through the consumption of sweet but lower-sugar products may satisfy an innate desire, and as a result, reduce subsequent desires for sweetness from other (potentially sugar-rich) sources (5–7). A robust body of evidence on sensory-specific satiety (8) shows that exposure to a particular sensory attribute (e.g., sweetness) can lead to reductions in the apparent pleasantness and choice of foods and beverages with that same attribute, relative to others. Thus, exposure to sweet taste from dietary sources with low amounts of sugars may not only replace consumption of free sugars, but could also reduce the desire for sweetness from other sources.

Theoretically, therefore, exposure to sweetness may stimulate, suppress, or have no net effect on an overall desire to consume sweet foods and beverages in the diet. Resolution of this issue is important for ensuring the most efficacious, evidence-based public health advice, with important implications for consumers and for the development of commercial food products reduced in sugars. Recent policy documents from the WHO and the Pan

American Health Organization have expressed a view that a reduction in exposure to sweetness could facilitate adaptation to lower sugar intakes, although no specific scientific underpinning is given (9, 10). In contrast, a review of literature by Public Health England in the UK concluded that there is little evidence for this suggestion (11). No systematic review of relevant evidence has yet been undertaken. The objectives of this work were to identify the evidence from human studies investigating the impact of dietary exposure to sweetness on the generalized acceptance, preference, or choice of sweet taste in the diet, draw conclusions with regard to the nature of the evidence and effects observed, and to highlight knowledge gaps and research approaches that could resolve these. Our specific research question was: does dietary exposure to sweetness in humans impact on the generalized acceptance, preference, choice, and/or intake of sweet taste in the diet?

METHODS

Searches

Three academic databases were searched over all years of records using 3 search strings. All search strings included a "sweetness" word ("sweet*" or "sugar*" or "fruit*" or "candy" or "chocolate" or "dessert" or "cake" or "biscuits" or "cookies" or "ice cream" or "ice-cream" or "pastr*" or "sucrose" or "fructose" or "glucose" or "tast*" or "sensory-specific" or "sensory specific" or "diet beverage" or "diet-beverage" or "juice" or "soft drink" or "yogurt" or "yoghurt") searched for in "title" fields; an "exposure" word ("expos*" or "diet*" or "experienc*" or "consum*" or "intake" or "ingest*") searched for in "title" or "abstract" fields; and an "outcome" word ("perception" or "intensity" or "threshold" or "sensitivity" or "prefer*" or "desire" or "lik*" or "want*" or "choice" or "accept*" or "rating*" or "selecti*" or "purchas*" or "crav*" or "consum*" or "intake" or "ingest*") searched for in "title" or "abstract" fields. Three search strings were used to allow the use of the terms "consum*," "intake," and "ingest*" as either an "exposure" or an "outcome" word, or as both "exposure" and "outcome" words. Full details of the 3 search strings are given in **Supplemental Material I**. All searches were conducted in PsychInfo and Food Science and Technology Abstracts (FSTA). Searches for all "exposure" and "outcome" words including "intake," "ingest*," and "consum*" were also conducted in PubMed. Searches for "intake," "ingest*," and "consum*" as both "exposure" and "outcome" words were conducted in Medline. This search was not possible in PubMed as a result of the Boolean operators required for the search, and Medline was used as the closest alternative. Searches for "intake," "ingest*," and "consum*" as both "exposure" and "outcome" words were also undertaken only for the "title" field, because multiple occurrences of exposure and outcome words would likely naturally occur in abstracts. Searches were limited to include only published articles, only articles published in English, and only articles about humans, when possible. Grey literature was not included. Terms relating to specific sugars, e.g., "sucrose," and specific sweeteners, e.g., "saccharin," were not included as search terms. Relevant studies were likely to include a search term that was already included, and thus the addition of these terms to the searches was considered likely to only result in the identification of irrelevant studies, e.g., safety studies, animal studies. Early search results were reviewed to assess their capture of known relevant articles, and modifications to the search terms and databases to be searched were made prior to the formal running of all searches. Reference lists of included articles were also searched for relevant articles not captured by the searches. Hand searching beyond this was not undertaken.

Article inclusion

Articles were suitable for inclusion in the review if they reported an investigation of the exposure to or a manipulation of sweet taste through foods and beverages in the diet, and a subsequent measure of perception (intensity), acceptance, preference, choice, and/or intake of sweet foods and beverages, in humans aged >6 mo.

Studies were required to include exposure to or a manipulation of sweet taste through foods and beverages in the diet [e.g., sugar-rich foods, low-energy-sweetener (LES)–sweetened foods or beverages, fruit], in which taste exposure was manipulated or measured using a validated method. Studies were required to measure explicit judgments of sweet stimuli and/or choice or intake behavior as outcomes, subsequent to exposure. Studies were included that investigated both relation between variation in exposure to sweet taste and variation in generalized acceptance, preference, choice, or intake of all or other sweet foods and beverages, e.g., population cohort studies; and that tested interventions manipulating the provision or restriction of sweet compared to nonsweet foods or beverages, e.g., randomized controlled trials. Cross-sectional observational research was not included, because outcomes in these studies were not measured subsequent to any taste exposure. Studies were required to include repeat (>1) taste exposures, and any duration between taste exposure and outcome was accepted. Studies could include any comparator (e.g., usual diet, nonsweet foods, nonsweet beverages), but a comparator must have been included. However, comparisons only to an earlier baseline measure or timepoint within the same treatment group or cohort were not included, i.e., studies with no separate control or comparison condition were excluded, due to the confounding of comparison with time period (e.g., 12, 13).

Outcomes could have been assessed using any validated (continuous or dichotomous) measure. Continuous measures included rating scales or weights of foods or beverages consumed, dichotomous measures included number of individuals selecting a sweet food item. Studies without explicit judgments or behavioral outcomes, e.g., studies measuring only neural representations of liking, were not included. Studies that did not include the assessment of responses to previously unexposed stimuli were also not included. These studies do not assess the potential for exposures to influence a generalized acceptance, preference, choice, or intake of sweet taste in the wider diet. Studies that included measurements of sweet and nonsweet foods as part of the study of appetite, without an a priori intention to measure sweet and nonsweet tastes separately, were not included (e.g., 14). Studies that confounded the effects of a sweet taste intervention with those of other interventions, e.g., an educational intervention, were also not included. Studies were restricted to those involving humans aged >6 mo, because a recent review addresses our research question in those aged ≤6 mo (15).

Article selection

Searches were conducted by one researcher (KMA or DJM) and duplicates were removed (KMA). Search results were then

screened by 2 researchers independently (EJB and DJM) based on title and abstract, and coded either "include" or "do not include." Only articles that received codes "do not include" by both researchers were discarded. Next, all articles identified as potentially relevant at this stage were accessed and screened for suitability by 2 researchers independently (DJM and EJB or HT). Articles were again coded "include" or "do not include" and discordances were discussed and resolved with a third researcher (KMA). Data on methodologic aspects of each study, outcomes, and risk of bias were subsequently extracted by 2 researchers independently (out of KMA, EJB, DJM, and HT). Discordances were discussed and resolved by the whole research team. Only published data were extracted; we did not attempt to contact study authors.

Review outcomes

Extracted data on methodological aspects for each study included the following: study publication date; study population and sample size; details of the sweet taste exposure or manipulation, including type and duration; details of the comparator; details of outcome measures; and duration between exposure and outcome. Extracted outcome data consisted of all findings on all relevant measures included in each study. Judgments on study outcome in relation to our research question and risk of bias were also recorded. Judgments on study outcomes were made by researchers because the majority of studies did not address our research question directly, and thus authors' conclusions were not always relevant. The conclusions of each study in relation to our research question were discussed and agreed on by the whole research team. Risk of bias was rated using 4 domains, based on the domains recommended by the Cochrane collaboration (16) and as used in other scales of study quality (e.g., 17). These domains were inclusion of adequate study power (inclusion of a power calculation, and that the study sample meets the numbers required); discrepancy between number of participants that enter the study [intention-to-treat (ITT) population] and number that are included in analysis (ITT analysis); discrepancy between number of participants that enter the study and number that complete the study (drop-out); and incomplete outcome reporting. These domains were selected as those that can be used to evaluate studies of a number of different study designs, as was likely to be required. For each domain, risk of bias was rated as "low," "high," or "unclear," based on published information, using the criteria given in **Supplemental Material II**.

Data synthesis

All extracted data were tabulated per study at the group level. Individual-level data were not sought. A narrative synthesis was conducted based on study design type. Further synthesis and combination, e.g., using meta-analysis, was not undertaken. Sufficient studies of any one design type were not available to allow meaningful statistical combination.

Review registration

A draft of our protocol was reviewed by 4 peers (of prominence in the field, but independent of the work), and their views were incorporated into the final protocol, registered with PROSPERO as CRD42016051840 on 24 November 2016 (18). Discrepancies

between our registered protocol and actual methods are given in **Supplemental Material III**. All methods were based on those suggested by the Cochrane Collaboration (16).

RESULTS

Search results

Initial searches were conducted on 24 June 2016. The most recent searches were conducted on 15 August 2017. Database searches resulted in the detection of 22,175 possible articles. Searching through reference lists of relevant articles also resulted in the identification of 2 articles. A total of 17,487 articles remained following deduplication. Of these, 68 full texts were assessed against our study inclusion criteria. Nineteen articles were finally included in our review. One article reported 2 separate studies (19) and another tested and reported children and adults as independent research study populations (20), yielding a final total of 21 studies that met our inclusion criteria. The results of all searches are provided in the PRISMA diagram in **Figure 1**.

Included studies

Twenty-one studies that could contribute to our research question were found: 7 population cohort studies and 14 controlled experimental studies or trials. These different types of evidence have been considered separately.

Population cohort studies

Included studies

Of the cohort studies, 3 studies involved retrospective measures of exposure (21–23), and 4 studies used prospective methods (24–27). Methodological details of these studies are given in **Table 1**. In the 3 retrospective studies, children were classified by either their exposure to sweetened foods (23), exposure to sweetened water (21), or a parental restriction of sweetened foods (22), as assessed using retrospective questionnaires for parents, and effects were compared to those who received a lower exposure or less restriction. In all studies, the comparator group received some exposure to sweet foods, due to the permitted consumption of naturally sweetened foods, e.g., fruit, during the exposure period. Studies assessed preferences (22, 23) and intakes (21) of sweetened beverages ≤21 mo after the period for which exposure was reported. In the 4 prospective studies, children were followed for 2–10 y. Assessments of exposure to sweetened weaning foods (25), fruit juice (27), sugar-sweetened beverages (26), and artificially and naturally sweetened beverages (24) were made at 6–9 mo, 12 mo, 16–25 mo, and 5 y, respectively, and exposure groups were subsequently compared to groups who received no exposure (24, 27) or lower exposure (25, 26) to the target foods, although other sources of sweet-tasting stimuli in the diet were again permitted in all studies. All 4 studies measured dietary intake of sweetened foods or beverages at later timepoints using validated self-report measures.

Findings

Findings from these 7 cohort studies are given in **Table 2**. Compared to groups with a lower exposure to sweet foods,
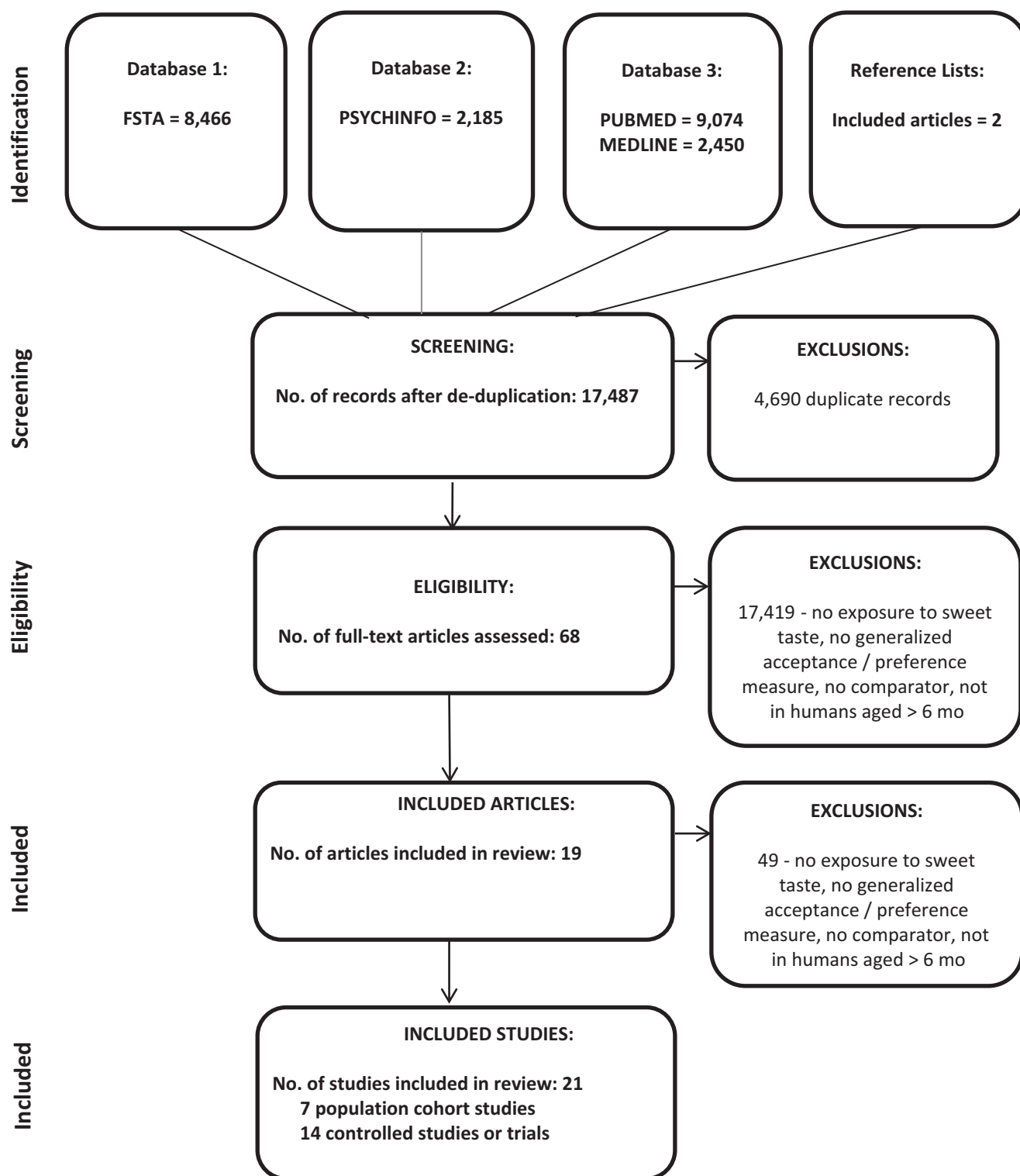
FIGURE 1 PRISMA diagram.

groups with a higher exposure to sweet foods reported lower (22) and higher (23) preferences for sweet foods (other than those involved in exposure), and higher (25–27), lower (24, 26) and no differences (21, 24, 26) in intakes of other sweet foods.

Risk of bias

Ratings of risk of bias are included in Table 2. For the domain considering adequate study size and power, ratings for population cohort studies were not applicable. Studies varied in rated risk of

TABLE 1
Longitudinal (retrospective and prospective) cohort studies investigating the impact of sweet taste exposure on subsequent assessments of a generalized preference for or acceptance of sweet taste: methodology[1]

Study (Ref)	Study population, age at E	E intervention	E intervention assessment	E comparator	A/R[2]	O	O assessment	Time from E to O	Other[3]
Liem et al. (22)	60 children (43 completers) aged 4–5 y	High restriction group (median split) based on reported frequency of restriction[4] (n = 22)	Parent completed FFQ[5] of 13 sweet foods for past month	Low restriction group (median split) based on reported frequency of restriction[4] (n = 21)	R	Preference for sweetness concentrations	Paired comparison test and rank ordering of 5 orangeades, of different concentrations of sucrose (0.14–0.61 M)	NR	—
Liem and Mennella (23)	83 children (80 completers)[6] aged 4–7 y	Mothers added sugar to child's diet on a routine basis (n = 51)	Parent-completed retrospective recall of behavior	Mothers never added sugar to child's diet (n = 29)	A	Preference for sweetness concentrations	Forced choice of pairs of 6 apple juices (10 mL) differing in sweetness (0.16–0.93 M sucrose). Number of times out of 15 that each child preferred the 3 sweetest juices	0	Preferences for sourness
Beauchamp and Moran (21)	63 black US children, aged 6 mo	Consumption of sucrose-sweetened water: 1) when <6 mo (n = 18) 2) when >6 mo (n = 29)	Parent-completed retrospective recall at 24 mo	Never fed sweetened water by 24 mo (n = 16)	A	Intake of plain vs. sucrose-sweetened water and fruit-flavored drink	Volume (mL) consumed of plain and sweetened water (0.2 and 0.6 M) and fruit-flavored drink (0.6 M) in laboratory setting	1) mean: 21.5 mo 2) mean: 12.2 mo	—
Foterek et al. (25)	288 children, aged 0.5–0.75 y	Percentage of g consumed from commercial/total complementary foods: 1) Medium tertile (43.1–71%)[7] 2) Highest tertile (>71%)[7]	3 consecutive days, detailed weighed diary at 0.5–0.75 y	Percentage of g consumed from commercial/total complementary foods: lowest tertile (≤43.0)[7]	A	Dietary intake of relative (% energy/d) and absolute (g/d) added sugar[8]	3 consecutive days, detailed weighed diary, at time of choosing	2–3 and 5–6 y	—
Sonneville et al. (27)	1163 children, aged 1 y	Fruit juice intake/d: 1) small: 1–7 oz (n = 619) 2) medium: 8–15 oz (n = 235) 3) large: 16 oz (n = 47)	Parent-completed questionnaire for past month	Fruit juice intake/d: none–0 oz (n = 262)	A	Dietary intake (servings/d) of fruit juice, and SSBs (soda, fruit drinks)	Semiquantitative child FFQ	2.1 y, 6.7 y	Water intake at E
Okubo et al. (26)	493 children in 3rd and 5th wave of study, aged 16–24 mo at 3rd wave	Exposure to SSBs (non-100% fruit juice, other sweetened juice)[9] at ages 16–24 mo: 1) 1–3/wk (n = 107) 2) 4–6/wk (n = 51) 3) >1/d (n = 57)	Parent-completed questionnaire assessing preceding month	Exposure to SSBs (non-100% fruit juice, other sweetened juice)[9] at ages 16–24 mo: <1/wk (n = 278)	A	Dietary intake, of fruit, confectionery, 100% FV juice, SSBs (fermented milk drinks, sugar-sweetened drinks, cocoa)	Brief dietary history questionnaire (FFQ of child's diet) translated to consumption g · 1000 kcal^{-1} · d^{-1})	~2 y (aged 41–49 mo)	—
Fiorito et al. (24)	170[10] non-Hispanic white girls, aged 5 y	Any LESB or SSB consumption at 5 y (n = 101)	3 × 24-h recall	No LESB or SSB consumption at 5 y (n = 69)	A	Dietary intake of milk, fruit juice, fruit drinks, soda, sweetened tea/coffee, and % added sugars	3 × 24-h recall, by mothers with girls at ages 5, 7, and 9 y, and by girls at ages 11, 13, and 15 y (unannounced telephone interview, within a 2- to 3-wk period)	2, 4, 6, 8, 10 y	—

[1] References were ordered by outcome measure, and then ascending length of exposure. A, addition; E, exposure; FFQ, food-frequency questionnaire; FV, fruit and vegetable; LESB, low-energy sweetener-sweetened beverage; NR, not reported; N/A, not applicable (cohort study); O, outcome; R, reduction; Ref, reference; SSB, sugar-sweetened beverage.

[2] Addition/reduction of sweet taste compared to comparator.

[3] All studies considered some demographic variables and included procedures to ensure methodologic quality to some degree. Column includes other outcomes assessed; risk of bias, power domain; N/A for cohort studies.

[4] Significant differences between reported high- and low-restriction groups on total sweet food consumption and sweet beverage consumption. Groups did not differ on mono- and disaccharide consumption, nor on consumption of candies or other foods.

[5] All FFQ foods contain added sugars—milk and fruit not included.

[6] Data provided for 80 completers, but 13/83 children reported as excluded.

[7] Significant differences between groups of relative (in % energy/d) and absolute (in g/d) added sugar from all complementary foods, and in total.

[8] Assessment only includes added sugars—natural sugars, e.g., in fruit, milk, and sugar substitutes and medicines not included.

[9] Groups consuming more SSBs at 16–24 mo also reported consuming more fruit and vegetable juice and more confectionery.

[10] Data provided for 170 children, but 166 complete data sets reported in the method section.

TABLE 2
Longitudinal (retrospective and prospective) cohort studies investigating the impact of sweet tastes exposure on subsequent assessments of a generalized preference for or acceptance of sweet taste: findings[1]

Study (Ref)	Outcome	Duration of E	Findings	Interpretation	RoB-ITT	RoB-D/O	RoB-IOR	Considerations/confounders
Liem et al. (22)	Preference for sweetness concentrations	1 mo at 4–5 y of age	Preferences for sweeter orangeades by high-restriction (low-exposure) group using both measures	Higher exposure to sweet foods (low-restriction group) is associated with lower preferences for sweetness	High	Low	Low	Demographic differences between groups
Liem and Mennella (23)	Preference for sweetness concentrations	Habitual at 4–7 y of age	Children whose mothers reported adding sugar to their foods on a routine basis preferred juices with added sugar	Higher exposure to sweetened foods is associated with higher preferences for sweetness	High	Low[2]	High[3]	Demographic differences between groups
Beauchamp and Moran (21)	Intake (mL) of plain vs. sucrose-sweetened water and fruit flavored drink in laboratory setting	Mean: 2.8–12.1 mo until 24 mo of age	Children fed sweetened water drank more sweetened water at age 2 y. No differences between groups in intakes of unsweetened or sucrose-sweetened flavored drinks	Exposure to sweetened water at <2 y of age is associated with higher intakes of same food, but not other sweet foods	Low	Low	High	More sweetened vs. plain-flavored drink consumed, regardless of exposure. No differences between groups in water intake. No effects based on anthropometry
Foterek et al. (25)	Dietary intake of relative (% energy/d) and absolute (g/d) added sugar	3 d (assumed habitual) at 0.5–0.75 y of age	Prospective associations between intake in infancy (% energy/d and g/d) and at 3–4 and 6–7 y of age. Associations lessen/disappear when added sugar and lifestyle factors are accounted for	Greater consumption of foods containing added sugar during infancy is associated with greater consumption later in childhood	Low	Low	Low	Models adjusted for demographic and lifestyle confounders
Sonneville et al. (27)	Dietary intake of fruit juice, and SSBs	1 mo (assumed habitual) at 1 y of age	Juice intake vs. no juice intake at age 1 y was associated with higher SSB (medium and large intakes) and juice consumption (all intakes) at ages 3 and 7 y (SSB and juice, all intake levels)	Higher consumption of juice in early childhood is associated with higher consumption of juice and SSB in later years	High	High	High	Demographic differences between groups. Models adjusted for confounders. No associations with water intake at 1 y of age
Okubo et al. (26)	Dietary intake including fruit, confectioneries, FV juices, SSBs	Past month (assumed habitual) at 16–24 mo of age	Greater intake of SSBs at 16–24 mo of age was associated with greater SSBs and confectionery intake, and lower fruit intake at 41–49 mo of age. No effects for 100% FV juices	Higher early SSB intakes are associated with later higher intakes of SSBs and some other sweet foods and lower intakes or no associations with other sweet foods	High	High	High	Demographic differences between groups. Models adjusted for confounders. Lower vegetable intakes with exposure also reported
Fiorito et al. (24)	Dietary intake of milk, fruit juice, fruit drinks, soda, sweetened tea/coffee, % added sugars	3 d (assumed habitual) at 5 y of age	Fruit juice, fruit drinks, sweetened tea/coffee, sodas: no differences between groups. Milk: greater reduction over time in nonexposed. Added sugars: greater reduction over time in exposed group	Differences between groups remain or reduce over time—no evidence of an association between exposure and future intake	High	Low	Low	Demographic differences between groups. Constant higher intake of soda in exposed group

[1] References ordered by outcome measure, and then ascending length of exposure. E, exposure; FV, fruit and vegetable; Ref, reference; RoB-D/O, risk of bias–drop-out domain; RoB-IOR, risk of bias–incomplete outcome reporting domain; RoB-ITT, risk of bias–intention to treat analysis domain; SSB, sugar-sweetened beverage.
[2] Data provided for 80 parent-child pairs, but 13 of 83 children are reported to have refused testing.
[3] Question asked about favorite candy, but data not reported (excepting 54% mother–child agreement).

bias for the other domains; the domain of ITT analysis was the most common potential source of bias of those assessed, and only one study was rated "low" risk for all 3 domains (25).

Controlled experimental studies or trials

Included studies

Fourteen studies used designs in which exposure to sweet foods was deliberately manipulated, 9 of which were relatively short-term (exposure for <1 mo or 28 exposures), whereas 5 studies involved daily exposure manipulations for 12 wk–6 mo. Methodologic details of these studies are given in **Table 3**. Of the shorter-term studies, 3 studies (28–30) used a within-subjects cross-over design, in which young, healthy, lean adults were exposed to only sweet foods (excepting tea and coffee) for 24 h (28), 5 consecutive breakfasts sweetened with sugar and 5 consecutive breakfasts sweetened with LES (29), or a portion of milk chocolate every day for 15 d (30). Impacts of these manipulations were compared to those of 24-h consumption of only salty foods, or a mix of sweet and salty foods (28), consumption of 5 consecutive unsweetened breakfasts (29) or a portion of french fries every day for 15 d (30). In the between-subjects studies, children and adults were randomly assigned to 8 d exposure to ≤200 mL sweetened beverages (20), 15 exposures (2 exposures/wk) to sweetened tofu (31), high restriction of 75 g (~20) chocolate coins for a weekend or chocolate Easter eggs for 2 wk (19), or daily exposure to milk chocolate for 22 d (32). Impacts of these manipulations were compared to 8 d exposure to sour beverages or no beverages (20), 15 exposures (2 exposures/wk) to salted tofu or plain tofu (31), low restriction of 75 g (~20) chocolate coins for a weekend or chocolate Easter eggs for 2 wk (19), or daily exposure to bread and butter (nonsweet) for 22 d (32). Only in the study by Griffioen-Roose et al. (28) was the sweet taste condition compared to an entirely nonsweet condition. In all other studies, exposure to other sweet foods were simultaneously permitted in all groups and conditions. Measured outcomes of relevance to our research question were: liking or pleasantness of sweet foods (other than those in the exposure manipulation) (28, 30, 32), appetite for sweet foods (28), explicit wanting or demanding sweet foods (19, 28), implicit wanting sweet foods (29), preferences for sweet foods (28, 30–32) or sweetness concentrations (20), and intake of sweet foods (19, 28–30).

In the longer-term studies, 124 healthy adults were randomly assigned to add milk chocolate daily to their diet for 12 wk compared to hazelnuts, salted potato chips, or no added foods (33), 50 infants were assigned to avoid products with added sugar for 3 mo compared to no avoidance (34), 33 overweight adults were randomly assigned to reduce simple sugar intake by 40% for 3 mo compared to usual diet (35), 210 overweight adults were randomly assigned to replace 2 servings/d of caloric sweetened beverages with water for 6 mo, compared to replacement with LES beverages (36), and 292 adults were randomly assigned to reduce sugar-sweetened beverage intake, compared to an activity intervention with no reported dietary instructions (37). Effects of the manipulations were assessed using measurements of: liking or pleasantness of sweet foods (other than those in the exposure manipulation) (33, 35), taste intensity and threshold detection tests for sweetness concentrations (35), preferences for sweet foods (34) and intake of sweet foods (34, 36, 37).

Findings

Findings from these 14 controlled studies are given in **Table 4**. In the majority of the shorter-term studies, sweet foods or beverages were added to the diet. Study groups and conditions with a higher exposure to sweet foods, compared to groups and conditions with a lower exposure to sweet foods, reported a relatively lower liking or pleasantness for sweet foods (28); a lower appetite for sweet foods (28); lower explicit and implicit wanting for sweet foods (28); higher demands (19) and no differences in the demands (19) for sweet foods; lower (28, 30) and no change (31) in preferences for sweet foods; no differences in most preferred sweetness concentration (20); and no effects on intakes (19, 28, 29). Conclusions could not be drawn from all relevant measures in all studies, because in some cases the results for (nonexposed) sweet and nonsweet foods were combined (30, 32).

In all longer-term studies, excepting that by Tey et al. (33), sweet foods or beverages were removed from the diet, though in none of these studies were sweet foods avoided entirely. The study groups with a lower exposure to sweet foods, compared to groups with a higher exposure to sweet foods, reported no differences in pleasantness or sweetness intensity rated most pleasant (35); perceptions of sweetness intensity as more sweet (while exposure was still manipulated), but no differences in threshold tests (35); no differences in preferences for sweet foods (34); no differences in intake of sweet foods (34); no differences in intakes of total sugars, added sugars, and sweetened drinks, but higher intakes of desserts (36); and no differences in intakes of total fruit, whole fruit and 100% fruit juice, but higher intakes of LES beverages (37). Conclusions could not be drawn from relevant measures as reported by Tey et al. (33), because results for (nonexposed) sweet and nonsweet foods were combined.

Risk of bias

Ratings of risk of bias are included in Tables 3 and 4. Studies varied in rated risk of bias for all domains considered. The domain of adequate study size and power was the most common potential source of bias of those assessed, for which only 2 studies received ratings of low risk (33, 35). For the domain of ITT analysis, risk of bias was rated as low in 6 studies (19, 20, 28, 29, 37). For the domain of drop-out, risk of bias was rated as low in all studies except 2 (31, 37). For the domain of incomplete outcome reporting, risk of bias was rated as low for all studies except 2 (30, 32).

DISCUSSION

The empirical evidence available addressing our research question was limited, comprising only 21 studies—7 population cohort studies involving 2320 children, and 14 controlled studies involving 291 children and 822 adults. This evidence was very heterogeneous and does not provide clear, consistent support for a relation between sweet taste exposures and the outcomes considered. Short-term interventions tended to find that greater exposure to sweetened stimuli leads to lower preferences for sweetness, but the results from cohort studies and longer-term intervention trials are limited and equivocal.

TABLE 3
Controlled experimental studies or trials investigating the impact of manipulated sweet taste exposure on subsequent assessments of a generalized preference for or acceptance of sweet taste: methodology[1]

Study (Ref); design	Study population	E intervention	E assessment	E comparator	A/R[2]	O	O assessment	Time of O assessment	RoB–P	Considerations[3]
Griffioen-Roose et al. (28); crossover, w/s	39 healthy lean adults (mean age: 21 y)	Fully controlled dietary intervention [except water, tea and coffee (no milk or sugar)]: sweet-tasting foods only[4]	24 h (1200–1200)	Fully controlled dietary intervention [except water, tea and coffee (no milk or sugar)]: 1) Savory-tasting foods only 2) Mix of sweet and savory tasting foods	A	1) Intake of 8 sweet and 8 savory foods 2) Explicit liking, explicit wanting, relative food choice and implicit wanting 3) Appetite for something sweet and something savory	1) Ad libitum buffet lunch meal intake (g) 2) Leeds Food Preference Questionnaire 3) 10-point Likert scales every hour during exposure	Immediately after the end of the 24 h	High	No data validating perceived intensity of sweetness and savoriness of diets. Also assessed: appetite
Mattes (29); crossover, w/s	24 lean young adults (mean age: 28.2 y)	Sweetened cereal (+ orange juice) every weekday/wk 1) Sucrose sweetened 2) Aspartame sweetened	5 consecutive days	Unsweetened cereal (+ orange juice) every weekday/wk	A	Intake – % energy from sweet, salty, sour and bitter food and drink: 1) Mean at next meal 2) Mean daily intake over 5 d	5-d diet records (with instructions not to alter customary diet)	Each weekday, from 3 h after breakfast (no eating allowed)	UC	All breakfasts equicaloric. Also assessed: liking, predominant taste of breakfast, total energy intake, appetite
Liem and de Graaf (20); children	63 (59) children (mean age: 9.2 y)	8 d exposure to ≤200 mL orangeade = sucrose + no citric acid (sweet) (n = 19)	8 d, ≤200 mL	1) 8 d exposure to ≤200 mL orangeade = sucrose + citric acid (sour) (n = 20) 2) No orangeade (control) (n = 20)	A	Preference for sugar concentration	Rank ordering of 7 orangeades and 7 lemon yogurts, with different concentrations of sucrose	After 8 d	High	Sweet and sour drinks rated equally pleasant
Liem and de Graaf (20); adults	46 adults	8 d exposure to ≤200 mL orangeade = sucrose + no citric acid (sweet) (n = 16)	8 d, ≤200 mL	1) 8 d exposure to ≤200 mL orangeade = sucrose + citric acid (sour) (n = 16) 2) No orangeade (control) (n = 14)	A	Preference for sugar concentration	Rank ordering of 7 orangeades and 7 lemon yogurts, with different concentrations of sucrose	After 8 d	High	Sweet and sour drinks rated equally pleasant
Hetherington et al. (30); crossover, w/s	25 (21) normal weight adults	Chocolate consumed 2 h after lunch for 15 d. Fixed intake (66 or 88 g/d for women or men) on days 2–4, 6–9, 11–14; ad libitum intake on days 1, 5, 10, 15	15 d	French fries consumed 2 h after lunch for 15 d. Fixed intake (92 or 122 g/d for women or men) on days 2–4, 6–9, 11–14; ad libitum intake on days 1, 5, 10, 15	A	1) Pleasantness 2) Preference of 8 sweet and nonsweet foods 3) Free-living intake of all 8 foods in 4 d prior to test day	1,2) Acute laboratory tests using bread and butter, pretzels, French fries, rice, pasta, jelly beans, chocolate, ice cream. Pleasantness: 100 mm line scale Preference: ranking 3) Retrospective FFQ	Days 1, 5, 10, 15	High	Not clear which test foods were classified as sweet or salty. Also assessed: intake on test days and pleasantness and desire to eat intervention food during exposure
Sullivan and Birch (31)	39 children aged 44–71 mo (mean age: 55 mo)	15 exposures, 2 times/wk of sweet tofu (14 g sucrose/100 g) (n = 14)	15 exposures, 9 wk	15 exposures, 2 times/wk: 1) Salted tofu (2 g salt/100 g) (n = 11) 2) Plain tofu (n = 14)	A	1) Preference for 6 foods: plain, salted, sweetened tofu, and ricotta cheese 2) Preference for 3 foods: plain, salted, sweetened jicama	1,2) Rank order of foods from "most liked" to "least liked"	1) Pre-exposure, after 8th and 15th exposure 2) After 15th exposure	High	—

(Continued)

TABLE 3 (Continued)

Study (Ref); design	Study population	E intervention	E assessment	E comparator	A/R[2]	O	O assessment	Time of O assessment	RoB-P	Considerations[3]
Ogden et al. (19); Study 1	53 children aged 1–7 y (mean age: 3 y)	75 g chocolate coins to give to child from 10:00 Saturday until end of Sunday, following restrictive rules[5,6] (restriction group) (n = 24)	2 d (∼20 coins)	75 g chocolate coins to give to child from 10:00 Saturday until end of Sunday, following nonrestrictive rules[5,6] (nonrestriction group) (n = 29)	R	1) Demanding chocolate coins (4 items) 2) Eating chocolate coins (4 items) 3) Demanding other sweet foods (4 items) 4) Eating other sweet foods (1 item)	All responses made on Likert scales from "Never" (1) to "Always" (5)	Start (first few hours) and day after, both recorded at time 2	High	No confirmation that sweet (milk, white) chocolate was used, but reference to "other" sweet foods. Also assessed: perceived and actual chocolate intake
Ogden et al. (19); Study 2	86 children aged 4–11 y (mean age: 7.5 y)	As study 1 but Easter eggs in place of chocolate coins,[6,7] for 2 wk; amount NR (restriction group) (n = 45)	2 wk	As study 1, but Easter eggs for 2 wk[6,7] (nonrestriction group) (n = 41)	R	1) Demanding chocolate coins (4 items) 2) Eating chocolate coins (4 items) 3) Demanding other sweet foods (4 items) 4) Eating other sweet foods (1 item)	All responses made on Likert scales from "Never" (1) to "Always" (5)	Start (first few days) and "shortly" after, both recorded at time 2	High	No confirmation that sweet (milk, white) chocolate was used, but reference to "other" sweet foods. No mention of control for other sweet Easter foods. Also assessed: perceived and actual chocolate intake
Hetherington et al. (32); Study 1	29 normal-weight, healthy men, mean age: 23 y	Milk chocolate for 22 d: ad libitum intake on day 1, 8, 15, 22; 67 g all other days (n = 13)	22 d	Bread and butter intake for 22 d: ad libitum intake on day 1, 8, 15, 22; 95 g all other days (n = 16)	A	1) Pleasantness 2) Preferences for 6 foods before and after ad libitum intake of intervention food 3) Frequency of intake of all test foods throughout exposure	1,2) Acute laboratory tests using milk chocolate, pretzels, bread and butter, cheese, jelly, ice cream. Pleasantness 100 mm scale. Preference: rank ordering 3) FFQ	Days 1, 8, 15, 22	High	Also assessed: ad libitum intake of intervention food during test days; pleasantness and desire to eat intervention food after a fixed intake
Tey et al. (33)	124 healthy adults	12 wk, 50 g/d (1100 kJ) milk chocolate (home exposure) (n = 33)	12 wk	1) 12 wk, 42 g/d (1100 kJ) hazelnuts (home exposure) (n = 32) 2) 12 wk, 50 g/d (1100 kJ) salted potato crisps (home exposure) (n = 28) 3) 12 wk, no additional food (n = 31)	A	Liking for 3 sweet and 3 savory foods (chocolate, marshmallows, cookies and hazelnuts, potato chips, salted pretzels), before and after acute ad libitum intake of intervention or random food	Acute laboratory tests. Measurements using 100 mm scales	Baseline, 12 wk	Low	Also assessed: daily overall liking, desire and FFQ of intervention foods over exposure; appetite before and after intake during test sessions; demographic variables

(Continued)

TABLE 3 (*Continued*)

Study (Ref); design	Study population	E intervention	E assessment	E comparator	A/R[2]	O	O assessment	Time of O assessment	RoB–P	Considerations[3]
Brown and Grünfeld (34); quasi-RCT[8]	50 infants, mean age: 3.8–4.1 mo at start	Mothers expressed desire to avoid sugar, given information and baby foods without added sugar (n = 25, 20 completers)	3 mo	Mothers who did not express a desire to avoid sugar[9] (n = 25, 20 completers)	R	1) Intake of sweetened and unsweetened baby foods supplied for home use (leftovers weighed) 2) Parents' perception of preferences	1) Grams consumed of baby foods (order randomized) 2) Parents' perception using 5-point scale (1 = low, 5 = high)	A 4-wk period immediately after 3-mo intervention	High	Unsweetened products were all naturally sweet. No control for possible energy differences between the diets
Wise et al. (35)	33 OW adults, regular consumers of SSBs (2/d)	Instructions to reduce simple sugar intake by 40% by increasing complex CHO, fats, protein. No replacing sugars with LES (n = 16)	3 mo (months 2–4)	Instructions to maintain usual diet (n = 17)	R	1) Taste intensity 2) Most preferred intensity 3) Pleasantness of 8 vanilla puddings and 9 raspberry beverages 4) Threshold detection	Taste intensity: 117 mm gLMS rating scales, and most preferred intensity Pleasantness: 23-point rating scale	During last 2 wk of each month	Low	Also assessed: assessments for control salty stimuli
Piernas et al. (36); secondary analysis of RCT	210 OW adults consuming ≥280 kcal/d from drinks	Replacement of 2 servings/d of SSB with water: 4 beverages/d provided (water group) (n = 108)	6 mo	Replacement of 2 servings/d of SSB with diet beverages: 4 beverages/d provided (DB group) (n = 105)	R	Dietary intake of total sugars, added sugars and sweet food groups—SSB and LES beverages; tea/coffee sweetened with LES and with sugar; desserts and sweeteners	2 × 24-h unannounced recalls within 14 d	3 and 6 mo from the start of the intervention	High	Part of an RCT for weight loss that also included an attention control group
Hedrick et al. (37); secondary analysis of RCT	292 adults consuming ≥200 kcal/d from SSBs	Reduce SSB intake to <240 mL SSB/d	6 mo	No dietary intervention or instructions reported (physical activity intervention)	R	Dietary intake of sweet food groups—SSBs, total fruit, whole fruit, 100% fruit juice, artificially sweetened beverages[10]	3 × 3-d dietary recalls by dietitian over the telephone, unannounced	3 and 6 mo from the start of the intervention	UC[11]	—

[1] References ordered by ascending length of exposure. A, addition; CHO, carbohydrate; DB, diet beverage; E, exposure; FFQ, food-frequency questionnaire; gLMS, generalized labeled magnitude scale; LES, low-energy sweetener; NR, not reported; O, outcome; OW, overweight; R, reduction; RCT, randomized controlled trial; Ref, reference; RoB–P, risk of bias–power domain; SSB, sugar-sweetened beverage; UC, unclear; w/s, within subjects.

[2] Addition/reduction of sweet taste compared to comparator.

[3] All studies considered some demographic variables and included procedures to ensure methodological quality, to some degree. Column includes other outcomes not relevant to our review that were assessed, and other considerations.

[4] Nonsweet foods, e.g., strong black coffee, were permitted.

[5] Food intake – actual (g) chocolate intake measured during the intervention. Mass consumed (mean 63 g vs. 37 g) confirms difference between restriction groups in exposure.

[6] No consideration appears to have been given for other sweet treats.

[7] Food intake – actual (g) chocolate intake measured during the intervention. Mass consumed (mean 693 g vs. 415 g) confirms difference between restriction groups in exposure.

[8] Intervention groups not randomly assigned: mothers chose which group to be in.

[9] Naturally sweetened foods were used for the comparison group.

[10] Food group analysis does not report many sweet food groups, including biscuit, cake, confectionery, and desserts.

[11] Power calculation provided, and number of participants met in one group, but in need of 2 participants in the other group.

TABLE 4
Controlled experimental studies or trials investigating the impact of manipulated sweet taste exposure on subsequent assessments of a generalized preference for or acceptance of sweet taste: findings[1]

Study (Ref)	Outcome	E duration	Findings	Interpretation	RoB–ITT	RoB–D/O	RoB–IOR	Notes
Griffioen-Roose et al. (28); crossover, w/s	1) Intake of 8 sweet and 8 savory foods at an ad libitum buffet lunch 2) Explicit liking, explicit wanting, relative food choice and implicit wanting 3) Appetite for something sweet, something savory	24 h	1) Trend toward lower intake of sweet vs. savory foods after sweet diet (P = 0.07) 2) Increased liking, wanting and preference for savory vs. sweet foods after sweet diet in all 4 measures 3) Lower appetite for something sweet during exposure to sweet diet vs. other diets	Consistent evidence of SSS-type effect, i.e., exposure to sweet vs. savory diet led to a reduced preference for (and trend to reduced intakes of) sweet vs. savory foods	Low	Low	Low	Appetite data combined across whole exposure period/condition for analysis, so not possible to disentangle effects of single/repeated exposure. No differences between conditions in total intake or number of foods/diet
Mattes (29); crossover, w/s	Intake – % energy from sweet, salty, sour and bitter food and drink: 1) Mean at next meal 2) Mean daily intake	5 consecutive days	1) No differences between conditions 2) Less energy consumed from bitter foods after sucrose (trend for LES) sweetened vs. unsweetened condition	No effect of sweet taste exposure on the intake of other sweet foods 3 h later or over whole day	Low	Low	Low	Both sweetened cereals were rated more pleasant than plain. Data combined across all study days/condition, so not possible to disentangle effects of single/repeated exposure
Liem and de Graaf (20); children	Preference for sugar concentration in 7 orangeades and 7 lemon yogurts	8 d, ≤200 mL	Increased preference pre-post for sweet orangeade in exposed group, not significant for yogurt. No changes for comparator	Repeated exposure increases preferences for sweetness in same food in children, but no transfer to other foods	High	Low	Low	No statistical between group comparisons. Sweet drink intake increased during exposure
Liem and de Graaf (20); adults	Preference for sugar concentration in 7 orangeades and 7 lemon yogurts	8 d, ≤200 mL	No change in preferences for any group	Repeated exposure does not change preferences for sweetness in adults	Low	Low	Low	No statistical between-group comparisons. Sweet drink intake decreased during exposure
Hetherington et al. (30); crossover, w/s	1) Pleasantness 2) Preferences for 8 sweet and nonsweet foods before and after ad libitum intake of intervention food 3) Intake of all 8 foods in preceding 4 d	15 d	1) Reduction in pleasantness of eaten vs. uneaten foods, but sweet vs. nonsweet foods not compared 2) Increased preferences for salty foods, decreased preferences for chocolate and other sweet foods 3) Data presented, analyses not presented	Exposure to sweet food led to decreased preference for that sweet food, and for other sweet foods. Not possible to draw conclusions based on measures of pleasantness or intake	High	Low	High	Decline in pleasantness and frequency of intervention food over exposure, but no change in ad libitum intake on test days

(Continued)

TABLE 4 (Continued)

Study (Ref)	Outcome	E duration	Findings	Interpretation	RoB–ITT	RoB–D/O	RoB–IOR	Notes
Sullivan and Birch (31)	1) Preference for 6 foods: plain, salted, sweetened tofu, and ricotta cheese 2) Preference for 3 foods: plain, salted, sweet jicama	15 exposures over 9 wk	1,2) Children preferred sweet ricotta cheese and sweet jicama, but no differences between exposure groups	Exposure impacts on preferences for same food, but has no impact on preferences for other sweet foods.	UC[2]	UC[2]	Low	Preferences for consumed food increased following exposure
Ogden et al. (19); Study 1	1) Demanding chocolate coins 2) Eating chocolate coins 3) Demanding other sweet foods 4) Eating other sweet foods	2 d (20 coins)	Reduced demanding and eating chocolate in both groups, and greater in nonrestricted group. Increased demands for other sweet foods in nonrestricted group compared to restricted group. No effects in eating other sweet foods	Exposure (lower restriction) reduces demand for same sweet food, but increases demand for other sweet foods	Low[3]	Low[3]	Low	—
Ogden et al. (19); Study 2	1) Demanding chocolate Easter eggs 2) Eating chocolate Easter eggs 3) Demanding other sweet foods 4) Eating other sweet foods	2 wk	Reduced demanding and eating chocolate in both groups, and greater effects in nonrestricted group. No effects for other sweet foods	Exposure (low restriction) reduces demand for same sweet food, but no effects on other sweet foods	Low	Low	Low	—
Hetherington et al. (32); Study 1	1) Pleasantness 2) Preferences for 3 sweet and 3 nonsweet foods before and after ad libitum intake of intervention food 3) Intake of all 6 foods in previous week	22 d	1) Decline in pleasantness of eaten vs. uneaten foods (data not split by sweet and nonsweet). No differences in this effect between intervention groups 2) Data presented for comparator only 3) No effects of condition found	Repeated exposure to a sweet food results in SSS effects in pleasantness to same sweet food, but effects on other sweet foods cannot be determined	High	Low	High	Decline in pleasantness and desire to eat intervention foods over the intervention period, no change in ad libitum intake
Tey et al. (33)	Liking for 3 sweet and 3 savory foods (chocolate, marshmallows, and cookies, and hazelnuts, potato chips, and salted pretzels), before and after acute ad libitum intake	12 wk	Reduced liking for eaten food in all intervention groups after 12 wk, and greater for chocolate group. Liking for uneaten foods remained constant, but analyses do not distinguish between sweet vs. savory test foods. Reduced SSS scores after 12 wk compared to baseline in all intervention groups, not for control group	Sustained repeated exposure to a sweet food reduces liking for and increases intake of that food, but has limited impact on other (sweet and savory) foods. Not possible to draw conclusions for other sweet foods	High	Low	Low	Intake of intervention foods increased between baseline and 12 wk. No effects in "desire to consume" but significant decrease in "overall liking" for chocolate over 12 wk

(*Continued*)

TABLE 4 (*Continued*)

Study (Ref)	Outcome	E duration	Findings	Interpretation	RoB-ITT	RoB-D/O	RoB-IOR	Notes
Brown and Grunfeld (34); quasi-RCT	1) Intake (g) of sweetened and unsweetened foods 2) Parents' perception of preferences	3 mo	1) No differences between or within groups for intake of sweetened vs. unsweetened foods[4] 2) No differences between or within groups	No effect of reduced exposure to sweetened foods on intake or preference for sweetened foods	UC	Low	Low	Intervention group consumed more food (total) in test period
Wise et al. (35)	1) Taste intensity 2) Most preferred intensity 3) Pleasantness of 8 vanilla puddings and 9 raspberry beverages 4) Threshold detection	3 mo	Increases in perceived intensity of low-sugar puddings (marginal for beverages) in low-sugar group in months 2 and 3 of diet manipulation—effects disappear on reversal to usual diet, no change for control group. No differences between groups in sweetness intensity rated most pleasant, pleasantness, or threshold tests	Reduced exposure to sweetness resulted in ratings of samples as sweeter after 2–3 mo, but no effects on pleasantness or thresholds	High	Low	Low	LES consumed by 4 (of 17) control and 2 (of 16) low-sugar participants
Piernas et al. (36); secondary analysis of RCT	Dietary intake of total sugars, added sugars and sweet food groups	6 mo	No group × time interactions for total sugar, added sugars, calorie-sweetened beverages, tea/coffee sweetened with LES, tea/coffee sweetened with sugar. More LES, LES drinks, and fewer desserts (at 6 mo only) consumed by DBS group than water group	Reducing sweetness exposure (water vs. DBS) led to relatively higher intake of one category of sweet foods but no effect on other sweet foods, total and added sugars	High	Low	Low	—
Hedrick et al. (37); secondary analysis of RCT	Dietary intake of sweet food groups—total fruit, whole fruit, 100% fruit juice, artificially sweetened beverages	6 mo	No group × time interactions for total fruit, whole fruit, 100% fruit juice. Significant group × time interaction for artificially sweetened beverages (increase for SSB group and decrease for comparator group). No data on other sweet foods in the diet	Reduced exposure to sweetness (SSB group vs. comparator) led to higher intakes of one category of sweet foods but no effect on 3 other sweet food categories.	Low	High	Low	—

[1] References ordered by ascending length of exposure. E, exposure; LES, low-energy sweetener; RCT, randomized controlled trial; Ref, reference; RoB–D/O, risk of bias–drop-out domain; RoB-IOR, risk of bias–incomplete outcome reporting domain; RoB–ITT, risk of bias–intention-to-treat analysis domain; SSS, sensory-specific satiety; UC, unclear; w/s, within subjects.
[2] Jicama assessment in subgroup (22/39) only. Not clear if this was intentional or not.
[3] Background data reported for only 52/53, or misreporting elsewhere.
[4] Lack of effects for sweetened vs. unsweetened food products may suggest a relatively high sweetness of all products.

Few studies were explicitly designed to test our research question, but instead addressed our question only indirectly (19, 22, 23, 25). Only 1 short-term study (28) directly compares exposure to sweetness with no exposure, whereas all other studies investigated the exposure or manipulation of ≥1 sweet foods or beverages within a background of additional sweet items. Few studies recorded subjective perceptions of the actual sweetness of the assessed foods or manipulations, and studies differed in their assessment or manipulation of amount compared to frequency of sweet taste exposure. Many studies measured limited outcomes (e.g., intake of only specific other foods) for limited time periods, and so may fail to account adequately for adjustments in the whole diet, and several studies assessed relevant outcomes but did not provide data in a suitable form to answer our question (30, 32, 33).

The best evidence available to address our research question is, arguably, that gained from the 4 randomized and 1 nonrandomized longer-term trials (33–37). These 5 studies provide limited evidence that lower exposure to sweet taste can increase the relative perceived sweetness intensity and intake of limited (other) sweetened foods or beverages in the diet. Consideration of only the studies of lower risk of bias further weakens the evidence supporting any effect. Only 2 studies (33, 35) were rated as sufficiently powered, although 2 others (36, 37) were large and reflect a realistic situation. These latter 2 studies, however, found significant effects in only one of several sweet food groups, no effects in other sweet food groups, and not all sweet food groups in the diet are reported. No differences in sweet food intake between groups were also found in 2 other studies (34, 35), but these studies suffer from some contamination between conditions.

Evidence was also available from 9 shorter-term experimental studies. One study reports increased demands for other sweet foods when sweet food consumption was higher (19), whereas all other studies report either no effects or lower preferences for sweet foods following higher exposure. All studies report no impact on sweet food intake. Consideration of only the studies of lower risk of bias reduces the evidence available, but supports these findings. Not all studies provided usable results (30, 32), and caution should be added to the findings from studies in which full control of the sweetness manipulation is not clear (19, 28), and in which effects of single and repeated exposures cannot be clearly distinguished (28, 29).

Lastly, 3 retrospective and 4 prospective population cohort studies of relevance were identified. Findings from these studies are inconclusive. Some evidence suggests an association between higher exposure to sweetness and subsequent higher preferences and intakes of sweet foods, but contradictory evidence is also available. Consideration of only the studies of lower risk of bias reduces the evidence available, but again provides equivocal results. Dietary intakes were rarely comprehensive, and often only "added sugars" or a few specific sweet foods or beverages were considered (22, 25). The studies identified were also notably all undertaken in children, in whom effects of sweet taste exposure may be difficult to see against a background of strong innate liking (15), and in whom differences in dietary intakes may reflect parenting practices and household food offerings, rather than preferences for specific sensory attributes. Preferences for sweet tastes are also known to reduce with age (2, 24), and therefore impacts demonstrated in childhood may not transfer to adulthood (15).

Potential mechanisms for a reduction in liking or intake of sweet stimuli following the short-term exposure to sweet taste are most likely based in sensory-specific satiety (8). Possible changes in sweetness perceptions as a result of sustained sweet taste exposure may suggest adaptations to taste receptors or transduction pathways (35), which in turn may result in increased intakes as a result of some form of habituation, tolerance or diminished reward [see (3) for a review]. Alternatively, the reporting of increased sweetness intensity against a background diet of low sweetness may demonstrate a simple contrast effect (38). Notably, the effects on sweetness intensity disappear when participants return to their usual diet (35), i.e., when the background diet reverts to higher levels of sweetness, whereas effects due to changes in physiology might be more likely to persist.

Comparison with other reviews

A review by Public Health England (11) reported associations between increased sweet taste exposure and increased preferences for sweet tastes in some studies, but no associations in other studies. We are aware of only one other formal systematic review which addressed our research question, conducted in humans <6 mo of age (15). This review also concluded that the evidence for a relation between early taste experiences and later acceptance for sweet taste was "equivocal" (15).

Future studies

The current evidence base is limited, and lacks large, adequately powered randomized trials of sufficient length to reflect habitual behavior. In the longer-term studies, impacts of sweetness manipulations were only found at 6 mo, not at 3 mo (36), or effects found after 2–3 mo disappeared the following month when participants were free to maintain a diet of their choosing (35). Furthermore, based on the limitations identified in this review, future studies should include assessments of the sensory attributes of dietary exposures or treatments, and distinctions should be made between exposure to sweetness in terms of frequency and duration and taste intensity and perception. Studies relevant to public health concerns and realistic in terms of different sources of sweetness are recommended.

Strengths and limitations of the review

Our conclusions are limited by the small body of literature, which provides an inconsistent picture. The review is limited through our consideration of only the published literature, of specific databases, and of articles published in English. We estimate however, that the majority of relevant work has been conducted in Europe or the United States, and so is likely to have been captured. We did not contact study authors, which may have limited our use of the literature available. We also have not used statistical techniques, e.g., meta-analyses, and made no appraisal of publication bias. Meta-analysis techniques were considered inappropriate due the indirect nature of much of the identified work and the low level of relevant data. We consider publication bias unlikely due to the equivocal evidence found, but this remains a possibility.

Conclusions

Our findings reveal a very limited, highly heterogeneous evidence base that addresses the impact of dietary exposure to sweet-tasting foods or beverages on the subsequent generalized acceptance, preference, or choice of these foods and beverages in the diet. The available evidence suggests possible reduced preferences for sweet taste following exposure in the shorter term, but limited and equivocal effects in the longer term. Given the public health and commercial relevance of the question, further research in the form of adequately powered clinical trials with well-characterized taste exposures is clearly required.

REFERENCES

1. World Health Organization. Guideline: sugars intake for adults and children. Geneva: World Health Organization; 2015.
2. Mennella JA, Bobowski NK. The sweetness and bitterness of childhood: Insights from basic research on taste preferences. Physiol Behav 2015;152:502–7.
3. Mattes RD, Popkin BM. Nonnutritive sweetener consumption in humans: effects on appetite and food intake and their putative mechanisms. Am J Clin Nutr 2009;89:1–14.
4. Sylvetsky AC, Dietz WH. Nutrient-content claims—guidance or cause for confusion? N Engl J Med 2014;371:195–8.
5. 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;6:4389–403.
6. 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;8:9.
7. Rogers PJ, Hogenkamp PS, de Graaf C, Higgs S, Lluch A, Ness AR, Penfold C, Perry R, Putz P, Yeomans MR, et al. 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;40:381–94.
8. Rolls BJ. Sensory-specific satiety. Nutr Rev 1986;44:93–101.
9. World Health Organization Regional Office for the Eastern Mediterranean. Website: http://www.emro.who.int/nutrition/strategy/policy-statement-and-recommended-actions-for-lowering-sugar-intake-and-reducing-prevalence-of-type-2-diabetes-and-obesity-in-the-eastern-mediterranean-region.html (accessed 13 April 2017).
10. Pan American Health Organization. Pan American Health Organization Nutrient Profile Model. Washington (DC): Pan American Health Organization; 2016.
11. Public Health England. Sugar Reduction: The evidence for action. Annexe 5: Food supply, 2015. Website: www.gov.uk. (Accessed: 5th July, 2017).
12. Sartor F, Donaldson LF, Markland DA, Loveday H, Jackson MJ, Kubis H-P. Taste perception and implicit attitude toward sweet related to body mass index and soft drink supplementation. Appetite 2011;57:237–246.
13. Bartolotto C. Does consuming sugar and artificial sweeteners change taste preferences? Perm J 2015;19:81–84.
14. Appleton KM, Blundell JE. Habitual high and low consumers of artificially-sweetened beverages: effects of sweet taste and energy on short-term appetite. Physiol Behav 2007;92:479–86.
15. Nehring I, Kostka T, von Kries R, Rehfuess EA. Impacts of in utero and early infant taste experiences on later taste acceptance: a systematic review. J Nutr 2015;145:1271–9.
16. Higgins JPT, Green S. Cochrane Handbook for Systematic Reviews of Interventions. 5.1 edition. Chichester, UK: The Cochrane Collaboration & John Wiley; 2011.
17. Jadad AR, Moore RA, Carroll D, Jenkinson C, Reynolds DJ, Gavaghan DJ, McQuay HJ. Assessing the quality of reports of randomized clinical trials: is blinding necessary? Control Clin Trials 1996;17:1–12.
18. Appleton K, Mela D, Bertenshaw E, de Graaf K, Tuorila H. Sweet taste exposures: effect on acceptance and preference for sweet taste in the diet. PROSPERO 2016: CRD42016051840.
19. Ogden J, Cordey P, Cutler L, Thomas H. Parental restriction and children's diets. The chocolate coin and Easter egg experiments. Appetite 2013;61:36–44.
20. Liem DG, de Graaf C. Sweet and sour preferences in young children and adults: role of repeated exposure. Physiol Behav 2004;83:421–29.
21. Beauchamp GK, Moran M. Acceptance of sweet and salty tastes in 2-year-old children. Appetite 1984;5:291–305.
22. Liem DG, Mars M, De Graaf C. Sweet preferences and sugar consumption of 4- and 5-year-old children: role of parents. Appetite 2004;43:235–45.
23. Liem DG, Mennella JA. Sweet and sour preferences during childhood: role of early experiences. Dev Psychbiol 2002;41:388–95.
24. Fiorito LM, Marini M, Mitchell DC, Birch LL. Girls' early sweetened carbonated beverage intake predicts different patterns of beverage and nutrient intake across childhood and adolescence. J Am Diet Assoc 2010;110:543–550.
25. Foterek K, Buyken AE, Bolzenius K, Hilbig A, Nothlings U, Alexy U. Commercial complementary food consumption is prospectively associated with added sugar intake in childhood. Brit J Nutr 2016;115:2067–74.
26. Okubo H, Miyake Y, Sasaki S, Tanaka K, Hirota Y. Early sugar-sweetened beverage consumption frequency is associated with poor quality of later food and nutrient intake patterns among Japanese young children: the Osaka Maternal and Child Health Study. Nutr Res 2016;36:594–602.
27. Sonneville KR, Long MW, Rifas-Shiman SL, Kleinman K, Gillman MW, Taveras EM. Juice and water intake in infancy and later beverage intake and adiposity: could juice be a gateway drink? Obesity 2015;23:170–176.
28. Griffioen-Roose S, Hogenkamp PS, Mars M, Finlayson G, de Graaf C. Taste of a 24-h diet and its effect on subsequent food preferences and satiety. Appetite 2012;59:1–8.
29. Mattes R. Effects of aspartame and sucrose on hunger and energy intake in humans. Physiol Behav 1990;47:1037–44.
30. Hetherington MM, Bell A, Rolls BJ. Effects of repeat consumption on pleasantness, preference and intake. Br Food J 2000;102:507–21.
31. Sullivan SA, Birch LL. Pass the sugar, pass the salt: Experience dictates preference. Dev Psycholol 1990;26:546–51.
32. Hetherington MM, Pirie LM, Nabb S. Stimulus satiation: effects of repeated exposure to foods on pleasantness and intake. Appetite 2002;38:19–28
33. Tey SL, Brown RC, Gray AR, Chisholm AW, Delahunty CM. Long-term consumption of high energy-dense snack foods on sensory-specific satiety and intake. Am J Clin Nutr 2012;95:1038–47.
34. Brown MS, Grunfeld CC. Taste Preferences of infants for sweetened or unsweetened foods. Res Nurs Health 1980;3:11–17.
35. 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;103:50–60.
36. Piernas C, Tate DF, Wang X, Popkin BM. Does diet-beverage intake affect dietary consumption patterns? Results from the Choose Healthy Options Consciously Everyday (CHOICE) randomized clinical trial. Am J Clin Nutr 2013;97:604–11.
37. Hedrick VE, Davy BM, You W, Porter KJ, Estabrooks PA, Zoellner JM. Dietary quality changes in response to a sugar-sweetened beverage-reduction intervention: results from the Talking Health randomized controlled trial. Am J Clin Nutr 2017;105:824–833.
38. Lawless HT. Contextual effect in category ratings. J Test Eval;11:346–349.