Reconsidering the classification of sweet taste liker phenotypes: a methodological review

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Title

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Abstract

Human ingestive behavior depends on myriad factors, including both sensory and non-sensory determinants. Of the sensory determinants, sweet taste is a powerful stimulus and liking for sweetness is widely accepted as an innate human trait. However, the universality of sweet-liking has been challenged. Sub-groups exhibiting strong liking (sweet likers) or having aversive responses to sweet taste (sweet dislikers) have been described, but the methods defining these phenotypes are varied and inconsistent across studies. Here, we explore the strengths and weaknesses of different methodological approaches in identifying sweet taste liker phenotypes in a comprehensive review. Prior studies ($N = 71$) using aqueous sucrose solution-based taste tests and a definition of two or more distinct hedonic responses reported between 1970 and 2017 were summarized. Broadly speaking, four different phenotyping methods have been used: 1. Interpretation (visual or statistical) of the shape of hedonic response curves, 2. Highest preference using ratings, 3. Average liking above mid-point or Positive/Negative average liking method, and 4. Highest preference via paired comparisons. Key methodological weaknesses included the use of subjective or arbitrary criteria as well as adoption of protocols unsuitable for large-scale implementation. Overall,

we did not identify a method distinctly superior to the others. Given the role of both hedonics and reward in food intake, a better understanding of individual variations in sweet taste perception could clarify how sweet-liking interplays with obesity or addictive behaviors such as alcohol misuse and abuse. The development of a universally used statistically robust and less time-consuming classification method is needed.

Keywords

Flavor perception; Gustation; Hedonics; Sugar; Sweet tooth; Taste preference

Abbreviations[1]

[1] BMI, body mass index; gLMS, generalized Labeled Magnitude Scale; HCA, hierarchical cluster analysis; s.d., standard deviation; SD, sweet dislike; SL, sweet liker; STT, sweet taste test; VAS, Visual Analog Scale

1. INTRODUCTION

Poor food choices and overeating are key contributors to the etiology of many modern chronic diseases, mainly by influencing the development of obesity and obesity-related conditions such as type II diabetes (Darnton-Hill, Nishida, & James, 2004; Swinburn et al., 2011). Human ingestive behavior involves a complex interaction between sensory and non-sensory factors. Biologically determined factors (taste, hunger/fullness mechanisms, sensory-specific satiety), experience/memory with food (physiological and social conditioning), person-related characteristics (perceptions, beliefs, values, knowledge, family and social networks etc.), and social and environmental determinants (cultural and religious norms; food availability, economic environment, public policies, media etc.) operate together and formulate discrete food choice patterns (Contento, 2016; Drewnowski, 1997; McCrickerd & Forde, 2016). Of the sensory determinants of food choice, sweet taste is widely accepted as a powerful stimulus that generally signals pleasure (Drewnowski, Mennella, Johnson, & Bellisle, 2012). According to the delay discounting theory (reviewed in Odum, 2011), this attribute of sweetness could presumably serve as an additional driver of food choice when immediate rewards (e.g. pleasure) are optimized over long-term benefits (e.g. health). Evidence from animal studies and human neuroimaging experiments suggest common neural pathways between addictive substances such as drugs and alcohol and sweet foods and beverages (Alonso-Alonso et al., 2015; Stice, Figlewicz, Gosnell, Levine, & Pratt, 2013), further supporting this key role for sweetness in food acceptance.

The pleasure derived from tasting sweet substances has been considered as an innate response evidenced by the positive facial reactions of newborns from a variety of species to the experience of sweet tastes (Desor, Maller, & Turner, 1973; Steiner, 1979; Steiner, Glaser, Hawilo, & Berridge, 2001). Sweet taste stimuli have been reported as more preferable even prior to birth (de Snoo, 1937; Liley, 1972). Although the underlying mechanisms have still to be fully determined, sweet taste liking has typically been hypothesized to have evolved as a signal for the presence of a safe source of energy to support development and survival (Mennella, Bobowski, & Reed, 2016).

The substance most commonly used to investigate the affective reactions elicited by sweetness is sucrose. During a laboratory-based sweet taste test (STT), various

concentrations of aqueous sucrose solutions are presented either individually in a randomized single-blind manner (Tables 1-4) or in a sequential dyadic manner (Table 5) in an attempt to determine the concentration perceived to be mostly preferred (see section 3.4 for additional details). As a rule, two or more replications of each series of solutions are completed, typically using a "sip and spit" protocol. In the traditional STT (individual presentation), participants rate the perceived liking of each solution before rinsing his or her mouth with water and proceeding to the next solution. The hedonic evaluation of each stimulus is collected using rating scales, although the choice of specific scale varies broadly between studies. The most widely used are either unipolar n-point category scales, or Visual Analog Scale (VAS) or similarly anchored lines scales where liking is rated on a continuous dimension between two extreme possibilities (e.g. "dislike extremely" and "like extremely"); such line scales may or may not include a defined neutral point in the middle (Tables 1-4). The hedonic version of the general Labeled Magnitude Scale (gLMS) and unbounded ratio scales (i.e., magnitude estimation) have also been used (Tables 1-4). Although there is no evidence that the use of a particular scale during a STT facilitates the identification of the distinct sweet taste liker phenotypes (Yeomans, Tepper, Rietzschel, & Prescott, 2007), considering that individuals may attribute different meaning to the same descriptor within a specific sensory modality, stripping away the internal labels from the rating scales could be beneficial (Hayes, Allen, & Bennett, 2013).

Researchers who use laboratory-based STTs have repeatedly described different hedonic responses to the same sweet taste stimulus, challenging the view that the expression of sweet-liking is universal. Early reports of these differential responses include those by Pangborn, and Thompson and colleagues, who observed different types of sweet liking responses after they tasted sucrose solutions of various concentrations (Pangborn, 1970; Thompson, Moskowitz, & Campbell, 1976, 1977). In later reports, a simpler distinction between SLs and SDs dominated. Alternative expressions such as low or moderate *vs*. high concentration likers, non-likers *vs*. likers and low *vs*. high preference group, as well as an additional grouping interpreted as a neutral hedonic response (the 'neutrals') have also been described. (Tables 1-5)

Despite some degree of conceptual agreement that distinct sweet taste liker phenotypes exist, the methods that have been used to identify these individual differences in affective responses to sweetness vary widely across studies. It is thus possible that the use of different methodological approaches to classify participants as sweet likers or dislikers contributes to inconsistencies in the literature regarding the relationship between sweet taste liker phenotypes and associated behaviors such as real life sugar intake (Holt, Cobiac, Beaumont-Smith, Easton, & Best, 2000; Methven, Xiao, Cai, & Prescott, 2016; Tuorila, Keskitalo-Vuokko, Perola, Spector, & Kaprio, 2017). Likewise, the interplay between sweet taste liker phenotypes and body weight (Asao et al., 2015; Malcolm, O'Neil, Hirsch, Currey, & Moskowitz, 1980; Thompson, et al., 1976; Yeomans, et al., 2007) or body composition (Coldwell, Oswald, & Reed, 2009; Drewnowski & Schwartz, 1990; Enns, Van Itallie, & Grinker, 1979; Mennella, Finkbeiner, Lipchock, Hwang, & Reed, 2014; Thai et al., 2011) remains inconclusive.

As the global health community is struggling to address obesity and its disease burden (Livingston, 2018), moving beyond the narrow view that liking for sweet taste is innate and universal and recognizing that people live in different hedonic worlds, could help in tailoring personalized treatments as well as targeted prevention policies. In the present paper, the various methods that have been applied for the identification of different sweet taste liker phenotypes are systematically reviewed, towards a goal of identifying the most consistent and usable methodology for future studies to adopt. To the best of our knowledge, this is the first methodological review that considers the strengths and weaknesses of the different sweet taste liker phenotyping methods.

2. MATERIAL AND METHODS

2.1 *Strategy & eligibility criteria*

A comprehensive review using a narrative approach was undertaken. To identify papers, a search was performed in January 2018 using two electronic databases: Scopus (https://www.scopus.com/) and MEDLINE/PubMed (https://www.ncbi.nlm.nih.gov/pubmed/). Search limiters included human subjects and studies being reported between 1960 and 2017. Databases were searched using the key words 'sweet taste', 'sweet liking', 'sweet taste liking', 'sweet preference', 'sweet taste test', 'sweet liker', 'sweet disliker', 'sweet taste phenotype', or 'hedonic' and 'sucrose'. Reference sections of the collected articles were manually scanned for additional relevant studies.

To be eligible for inclusion, a clear definition of two or more different categories of sweet taste liker phenotypes which were based on liking ratings of aqueous sucrose solutions was required. Studies classifying participants into different liking quartiles based on their responses to food, complex beverages or flavoured/coloured sweet solutions, either after they tasted the stimuli or after they completed relevant preference questionnaires, were beyond the scope of this review and were excluded. It should be noted that sensory perceptions of "real life" food and beverages are highly influenced by memory, experience, and product familiarity (Mela, 2001; Ventura & Worobey, 2013). Moreover, many sweet food products used in those studies are also high in fat (chocolate, cake, biscuits, ice cream etc.) with some evidence suggesting an effect of sugar on the sensory assessment of fats and vice versa (Drewnowski & Almiron-Roig, 2010; Hayes & Duffy, 2007, 2008; Mennella, Finkbeiner, & Reed, 2012). The impact of the food matrix (Urbano et al., 2016), as well as of the tastants' spatial distribution (Mosca, Bult, & Stieger, 2013) on sweet taste perception have also been argued. Therefore, to ensure the approach taken truly identified responses solely to sweet taste, only studies conducted with simple sucrose solutions were included in this review.

To better assist methodological driven comparisons and reduce the diversity in taste test protocols, experiments which attempted to classify participants into distinct sweet-liking groups using sweet tastants other than sucrose (e.g. in Looy, Callaghan, & Weingarten, 1992; Oleson & Murphy, 2017; Thai et al., 2011; Yeomans, Prescott, & Gould, 2009) were also

excluded. Firstly, many consumers detect other taste or flavour elements when tested with artificial sweeteners, such as the well-known concentration-dependent bitterness of acesulfame potassium and saccharin (Bobowski, Reed, & Mennella, 2016; Horne, Lawless, Speirs, & Sposato, 2002; Roudnitzky et al., 2011; Schiffman, Booth, Losee, Pecore, & Warwick, 1995; Schiffman, Reilly, & Clark, 1979), and so phenotypic differences in response to these compounds could reflect differences in sensitivity to these subtle non-sweet flavour elements. Secondly, although psychophysical evidence has suggested considerable similarity in the actions of all simple sweeteners on sweet taste receptors (Fernstrom et al., 2012), different pathways have been implicated with the detection and recognition thresholds of sugars and non-nutritive sweeteners (Low, McBride, Lacy & Keast, 2017). Pragmatically, we also recognised that the vast majority of studies have used sucrose as the sweet tastant. As long as taste protocols controlled for potential effects of ingestion and, therefore, the potentially diverse metabolic effects and effects on gut-brain axis elicited by different sweeteners (Low, Lacy & Keast, 2014; Rother, Conway, & Sylvetsky, 2018; Tucker & Tan, 2017) were minimized, it could be hypothesized that the current review's conclusions on the strengths and weaknesses of the sweet taste liker phenotypes classification methods based on sucrose-based taste tests could be used more broadly. Moreover, studies directly contrasting the distribution of sweet taste liker phenotypes using different sweeteners report highly overlapped figures (Looy, Callaghan, & Weingarten, 1992; Oleson & Murphy, 2017; Thai et al., 2011). Conversely, recent evidence suggesting that complex carbohydrates can be perceived independently of the sweet taste oral receptors (Lapis, Penner, & Lim, 2016) and that gustatory sensitivity to simple sugars might be, at least in part, dissociated from that of complex carbohydrates (Lapis, Penner, & Lim, 2014; Low, Lacy, McBride, & Keast, 2017) does however suggest some caution needs to be used in interpretation of the cause of differences in sweet-liker phenotypes based on evaluation of sucrose.

2.2 *Analysis of different methodological approaches*

Most of the eligible studies used a single method to identify different sweet taste liker phenotypes; accordingly, a methods-based structure was chosen to organize the eligible papers, versus a purely chronological summary. For each method, the relevant studies are

discussed and their main characteristics are summarized in a table (Tables 1-5). In cases that used more than one method on the same group of participants, those studies are included in the relevant tables for each method they used. To assess the impact of these different approaches on phenotype identification, the proportions of the main sweet taste liker phenotypes are graphically presented (Figure 2). A discussion of the strengths and weaknesses of each classification approach follows, along with recommendations for future research.

2.3 *Statistical analysis*

Across the studies reviewed, the proportions of individuals within each phenotype varied. These differences could be due to either the sensitivity of the method, or may reflect underlying differences in characteristics of the participant cohort being tested. To assess these hypotheses, two-tailed Z-tests for independent samples (Formula 1) were conducted to determine whether sweet taste liker phenotypes and sex significantly differed across classification methods. The formula used considers the best available estimate for the variance of each pairwise difference under the null hypothesis. Differences in age and BMI between methods were estimated by non-parametric Kruskal Wallis tests (H) for independent samples, followed by Mann Whitney post-hoc tests with adjusted *p-values*. To account for the different sample sizes, raw age and BMI mean values were transformed into z-scores before these analyses (Formula 2). Effect sizes were calculated for the pairwise comparisons by dividing the Z statistic of the Mann Whitney test with the squared root of the study samples being relevant to each comparison (Field, 2013). Participants' characteristics are reported as percentages in case of categorical variables and as means (M) ± standard deviations (s.d.) for continuous data. All values were weighted based on the different sample sizes as seen below (Formula 3-5).

$$Z = \frac{(P_1 - P_2)}{\sqrt{\hat{P}(1-\hat{P})\left[\frac{1}{N_1} + \frac{1}{N_2}\right]}} \text{ for null hypothesis } (H_0)\text{: } P_1 = P_2 \text{ and } \hat{P} = \frac{N_1P_1 + N_2P_2}{N_1 + N_2}$$

Formula 1. Equation for z-statistic for independent proportions (Z)

$$Z\ score = \frac{M - M_{pooled}}{s.d.}$$

Formula 2. Equation for z-score estimation (*Z score*)

$$P_{pooled} = \frac{N_1P_1 + N_2P_2 + \ldots + N_kP_k}{N_1 + N_2 + \ldots + N_k}$$

Formula 3. Equation for pooled percentage estimation (P_{pooled})

$$M_{pooled} = \frac{N_1M_1 + N_2M_2 + \ldots + N_kM_k}{N_1 + N_2 + \ldots + N_k}$$

Formula 4. Equation for pooled mean estimation (M_{pooled})

$$s.d._{pooled} = \sqrt{\frac{(N_1 - 1)s.d._1{}^2 + (N_2 - 1)s.d._2{}^2 + \ldots + (N_k - 1)s.d._k{}^2}{(N_1 + N_2 + \ldots + N_k) - k}}$$

Formula 5. Equation for pooled standard deviation estimation ($s.d._{pooled}$)

Where:

- P_1, P_2, …, and P_k are the samples' proportions that have the characteristic in question
- N_1, N_2, …, and N_k are the samples' size
- k is the number of independent samples
- *M* is the mean
- *s.d.* is the standard deviation

Studies with missing or incomplete data and those using incompatible measures (e.g. BMI percentiles or categories instead of BMI raw values, median instead of mean values, etc.) were excluded from analysis. To ensure the independence of the various study cohorts, studies with stated or suspected overlap in sampling were excluded. All formula-based calculations were performed in Microsoft Excel 2013 software for Windows. Remaining

analyses were carried out using IBM SPSS Statistics version 24.0. An alpha level of .05 was considered for all statistical tests.

3. RESULTS

3.1. Identification of key methodological approaches to classifying sweet taste liker phenotypes

Our literature search identified sixty nine relevant papers describing seventy one studies that met the eligibility criteria including fourteen manually retrieved from the reference lists of the search results; 256 records in Scopus and 192 records in MEDLINE/PubMed were excluded after the screening process was completed. After adjusting for possible overlapping samples, 7543 subjects (37% men; data from 61 studies) who were tested for their hedonic responses to sweet taste and classified to different sweet taste liker phenotypes were included into the final analysis. All but six studies recruited only adults. Average age and BMI for adults were 31.9 years (*s.d.* = 10.3 years; data from 46 studies) and 26.9 kg/m^2 (*s.d.* = 6.6 kg/m^2; data from 24 studies), respectively. Research groups from the United States published the most (63%), followed by studies in the UK and elsewhere.

Across the eligible papers four different classification methods were identified: 1a. Visual discrimination of hedonic responses to multiple sucrose concentrations (*N* = 23 including 2 studies that used two classification methods; Table 1) where individual liking ratings are plotted as a function of concentration, 1b. Statistical discrimination of hedonic responses to multiple sucrose concentrations (*N* = 5; Table 2) where participants are statistically merged to homogenous groups based on their hedonic responses, 2. The 'highest preference using ratings' method (*N* = 32; Table 4) where the specific sucrose concentration associated with the highest liking rating was identified, 3. The 'average liking above mid-point' or 'positive/negative liking' method (*N* = 10 including 1 study that used two classification methods; Table 4) where liking ratings are compared to a particular cut-off score, and 4. The 'highest preference via paired comparisons' method (*N* = 5 including 1 study that used two classification methods; Table 5) where the sucrose concentration of optimal palatability is identified. These different approaches are described in detail in the subsequent sections.

Study populations also vary across methods. One reason for this is that some methodological approaches tend to be used consistently in particular academic fields of study. For example, Method 2 has been widely used in studies relating sweet taste responses to medical

conditions such as alcoholism, a disorder being more prevalent among males (NSDUH, 2017). In contrast, Methods 1b and 3 are often used by researchers investigating different aspects of sweet-liking such as associations with other sensory characteristics in healthy (i.e. medication free) non-smoking individuals and, correspondingly, young (Kantor, Rehm, Haas, Chan, & Giovannucci, 2015; Moody & Mindell, 2017) women (Jamal et al., 2016; OPN, 2018) of relatively low BMI (Conolly & Saunders, 2017; Fryar, Carroll, & Ogden, 2016) dominate in those cohorts. Accordingly, as can be seen in Table 6, sex distribution differed significantly between methods across all but two pairwise comparisons (Method 4 *vs*. Method 1a: $Z = 0.87$, $p = .384$; Method 4 vs. Method 2: Z = 1.93, p = .054; $p < .05$ for remaining comparisons). Just over half of those who were assessed via the 'highest preference' rating method were men (51.1%), whereas the largest sex disparity was observed in studies using the 'average liking above mid-point'/'positive/negative liking' method with barely one out of 4 participants being men (22.9%). Likewise, BMI and age were significantly different across the various classification methods, $H(3) = 12.30$, $p = .006$, and $H(3) = 9.37$, $p = .025$, respectively. Note that because full data were only available from a study testing a paediatric population, Method 4 was not included in these comparisons. Follow-up analysis indicated that in studies using Method 2, participants had a considerably greater body size compared to those in Method 1a ($p = .001$, $r = .583$), and participants tested were also significantly older than those in Method 1a and 3 ($p = .014$, $r = .299$; $p = .013$, $r = .363$, respectively). Method 3 tended to test individuals with a lower BMI when contrasted with Method 1b ($r = .756$, $p = .064$). Overall, comparisons of age yielded slightly smaller effect sizes relative to the BMI contrasts.

3.2 *Classification by interpreting the shape of individual hedonic response curves (Method 1a & Method 1b)*

The interpretation of the shape of individual hedonic response curves to different sweet taste stimuli was the first methodology used to identify distinct sweet taste liker phenotypes, following a seminal report by Pangborn (1970). In brief, liking ratings (or average liking ratings in case of replicates) across different stimuli are plotted so that the effects of increasing sucrose concentration (x-axis) on the perceived liking at individual level (y-axis)

can be visually inspected. A simplified summary of the most commonly reported sweet taste liker phenotypes resulting from visual inspection of the shape of these individual hedonic response curves is shown in Figure 1.

3.2.1 *Visual discrimination of hedonic responses to multiple sucrose concentrations (Method 1a)*

Simple visual interpretation of response curves to classify participants into different groups presumed to reflect different sweet taste liker phenotypes prevailed for more than four decades (Table 1). In 1970, Pangborn observed three distinct hedonic responses to increasing sucrose concentrations among men: increased liking ('like'), increased disliking ('dislike'), and increasing liking ratings followed by a reduction for solutions with added sucrose above 0.094 M ('like-dislike': Pangborn, 1970). When a range of stronger sucrose solutions was presented to an age diverse population including both men and women, although the intermediate ('like-dislike') phenotype was associated with a three times higher breakpoint, an otherwise consistent set of results was revealed (Enns, et al., 1979). Specifically, the 'liker' phenotype was dominant in both experiments (55.0 and 63.3%, respectively), while the remaining of the participants were split roughly equally between the two other phenotypes. Age and sex differences aside, participants in Pangborn (1970) also tasted nearly twice as many solutions (replicates included) as those in Enns et al. (1979); adaptation (Lawless & Heymann, 2010) and sensory specific satiety (Rolls, Rolls, Rowe, & Sweeney, 1981) could, then, partially explain the qualitative difference observed regarding the intermediate phenotype. A subsequent study exclusively in women using a similar range of sucrose concentrations as Enns and colleagues (1979) but reporting a sucrose concentration breakpoint closer to that of Pangborn (1970), identified the same three sweet taste liker phenotypes, but failed to confirm these particular proportions (Franko, Wolfe, & Jimerson, 1994). Half of those women had a current diagnosis of bulimia nervosa which is likely to underlie altered or biased sensory evaluations (Drewnowski, 1989).

Those three sweet taste liker phenotypes continue to be reported in more recent studies (Table 1). However, participants who exhibit either an increasing disliking or an inverted U-shaped hedonic pattern are now typically considered as a single group, the SD phenotype.

Interestingly, although relevant cohorts mainly consisted of young women of normal body weight and the concentration range of sweet taste stimuli tested was relatively similar, the representation of SL-SD phenotypes significantly varied: it ranged between 3:1 in Yeomans et al. (2007) to 1:5 in Holt et al. (2000), with almost a 50-50 proportion observed elsewhere (Drewnowski, Henderson, Shore, & Barratt-Fornell, 1997; Oleson & Murphy, 2017). This lack of concordant findings with regard to the number of SLs and SDs identified in studies where this oversimplifying merging occurred, is probably indicative of the implications of the subjectivity attached to visual inspection-dependent methods.

In contrast, Thompson and colleagues (1976) recognized only two different phenotypes when they visually interpreted the hedonic response curves to sweet taste stimuli; an inverted U-shaped curve characterized by an increased liking up to a sucrose concentration equal to 0.30 M and then a decline (Type I response/phenotype) and an increased liking with concentration (Type II response/phenotype). When they replicated their protocol in another sample of young adults, a similar 70:30 Type I to Type II sweet taste liker phenotypes proportion to that of Group 1 in Thompson et al. (1976) was observed (Thompson, et al., 1977). In the other studies that used the same classification methodology (Drewnowski & Schwartz, 1990; Grinker & Hirsch, 1972; Johnson, Keane, Bonar, & Downey, 1979; Malcolm, et al., 1980; Thai, et al., 2011; Travers et al., 1993), different proportions of Type I and Type II responders, or sweet dislikers (SDs)-sweet likers (SLs) as they were subsequently renamed by Drewnowski & Schwartz (1990) were reported. It should be noted, though, that except the comparable sucrose concentration breakpoint observed in the Type I responders (0.18-0.32 M), participant characteristics greatly varied across the different studies (Table 1).

A potentially replicable methodology was suggested when the SL-SD classification was attributed to individuals exhibiting a simple monotonically ascending and monotonically descending hedonic function to increasing sucrose concentration; SLs were systematically outnumbered by SDs (Drewnowski, Henderson, Shore, & Barratt-Fornell, 1998; Drewnowski, Henderson, & Shore, 1997; Eikemo et al., 2016; Grinker, 1977; Looy, Callaghan, & Weingarten, 1992; Looy & Weingarten, 1991, 1992). It is noteworthy that in the studies by Looy and colleagues, although additional sweet taste liker phenotypes were also identified,

no further details on those subjects exhibiting either a neutral, an erratic, or an inverted U-shaped response were provided.

3.2.2 *Statistical discrimination of hedonic responses to multiple sucrose concentrations (algorithmic classification: Method 1b).*

To overcome the possible limitations resulting from the subjective visual discrimination of the different sweet taste liker phenotypes, a statistically-based approach has been suggested recently (Table 2). The hierarchical cluster analysis (HCA) technique produces relatively homogeneous sub-groups (clusters) of cases based on selected characteristics either through an agglomerative (successive fusion of individuals into groups) or a divisive (successive separation of individuals into finer groups) approach (Everitt, Landau, Leese, & Stahl, 2011). Essentially, this method determines how many likely clusters of data are present in the dataset based on the statistical relationship between liking ratings and sucrose concentration for each individual. Wherever the information has been available (Asao, et al., 2015; Garneau, Nuessle, Mendelsberg, Shepard, & Tucker, 2018; Methven, et al., 2016), the agglomerative method was selected, i.e. hierarchical decomposition was formed in a "bottom-up" fashion.

Researchers in Korea were the first to introduce the use of HCA in the relevant literature (Kim, Prescott, & Kim, 2014). In their initial experiment in a sample of young healthy Korean women three clusters were recognized: two clusters where both the hedonic response curves followed the inverted U-shaped pattern but with different breakpoints (0.35 and 0.70 M), and one with increasing liking with increasing sucrose concentration (Kim, et al., 2014). It should be noted that in Cluster 2 the gap between the highest and the lowest ratings was only 2 points, similar to the neutral response noted using the visual inspection method discussed earlier. When the protocol was replicated in a comparable study sample (Kim, Prescott, & Kim, 2017), five clusters were reported and interpreted as three distinct sweet taste liker phenotypes evenly distributed across participants. However, unlike their first experiment, only one inverted U-shaped pattern was observed with the maximum liking at

0.35 M. A strong disliking (SDs) and a strong liking (SLs) pattern were also reported each representing approximately one third of the study sample.

Irrespective of the divergent representation of the distinct sweet taste liker phenotypes, the relatively steep increasing slope with increasing sucrose concentration (SL phenotype) was also consistent across the rest of the experiments using HCA (Table 2). In a US-based large-scale study of 953 participants from various ethnicities and age groups (Garneau, et al., 2018) children's hedonic responses were classified into two clusters: a SL cluster representing 3 out of 4 children and a second cluster for those with a SD phenotype. HCA for the adults' sub-group revealed an additional cluster that included both individuals with a relatively neutral liking pattern and those with the inverted U-shaped hedonic response (40.3% and 17.7% of the total adult sample, respectively). In Methven et al. (2016) where only two clusters of hedonic responses were identified among UK adults, there were almost half as many SLs as there were SDs. It is worth mentioning that ratings for the two lower sucrose concentrations were only slightly above neutral across those SDs. Another study with a similar small sample size as that in Methven et al. (2016) but which used double the number of sweet taste stimuli, reported an equal number of SLs and SDs in a US cohort (Asao, et al., 2015). SD phenotype was, however, expressed by a definite inverted U-shaped hedonic response curve.

3.3 *Highest preference using ratings classification method (Method 2)*

Identifying the sweet taste stimuli associated with the highest preference using ratings from a small set of samples (see Table 3 for the range of stimuli used) and accordingly assigning participants into particular sweet taste liker phenotypes is another commonly used classification method. Following the lead of Kampov-Polevoy and colleagues as originators of this approach (Kampov-Polevoy, Garbutt, Davis, & Janowsky, 1998; Kampov-Polevoy, Garbutt, & Janowsky, 1997), most subsequent studies investigating links between sweet liking and addictive behaviors or mental disorders have used a similar approach. Two distinct sweet taste liker phenotypes were described: a SL phenotype and a SD phenotype. The SL phenotype was defined as preferring the highest sucrose concentration (or the two

higher sucrose concentrations) typically being at 0.83 or 0.97/0.99 M, whereas subjects rating one of the remaining concentrations (or one of the two lower concentrations) as the most likable were classified as SDs.

A first screening for addiction-related experiments listed in Table 3 revealed that in 6 out of 8 studies under a case-control design that tested participants with a diagnosed alcohol or substance dependence, SLs represented more than 50% of the total study sample (Bogucka-Bonikowska et al., 2001; Kampov-Polevoy, et al., 1997; Krahn et al., 2006; Kranzler, Sandstrom, & Van Kirk, 2001; Tremblay, Bona, & Kranzler, 2009; Wronski et al., 2006). Notably, in half of those studies, the classification criteria that were used for the identification of the distinct sweet taste liker phenotypes may influence the final count in favor of the SL group. For example, Kampov-Polevoy and colleagues (Kampov-Polevoy, et al., 1997) and Kranzler and colleagues (Kranzler, et al., 2001) attributed the SL phenotype to subjects expressing preference for either the first or the second highest sucrose concentration, while Tremblay and colleagues (Tremblay, et al., 2009) used a much stricter definition for the SDs (maximum liking rating for the lowest sucrose concentration). The two remaining addiction-related studies are split between those where the two discrete sweet taste liker phenotypes were evenly distributed across participants (Bogucka-Bonikowska et al., 2002), and those where SLs were less than one third of the total study sample (Kampov-Polevoy, et al., 1998).

Regarding studies testing psychiatric patients and their matched healthy controls, regardless of the heterogeneity in age and underlying disorders, less variability among the proportions of the distinct sweet taste liker phenotypes was reported. In these studies, SLs were either more than (Sienkiewicz-Jarosz et al., 2013; Swiecicki et al., 2015; Swiecicki et al., 2009) or as many as (Damiano et al., 2014) the SDs in all but one (Dichter, Smoski, Kampov-Polevoy, Gallop, & Garbutt, 2010) study. Unlike with the addiction-related trials, women overall outnumbered men, while in Sienkiewicz-Jarosz et al. (2013), Swiecicki et al. (2015), and Swiecicki et al. (2009), where a higher proportion of SLs was reported, a sweet taste test protocol including three different sucrose solutions being served twice (i.e. a 3 x 2 design) was used instead of the more commonly used 5 (sweet taste stimuli) x 5 (replicates) design. Accordingly, it is not unreasonable to speculate that individuals are more likely to be

classified as having the SL phenotype when tested in a protocol with less opportunity for fatigue, adaptation (Lawless & Heymann, 2010) and sensory specific satiety effects (Rolls et al., 1981).

Confirming this hypothesis, non-case-control addiction-related studies (Garbutt, Kampov-Polevoy, Kalka-Juhl, & Gallop, 2016; Janowsky, Pucilowski, & Buyinza, 2003; Kampov-Polevoy, Eick, Boland, Khalitov, & Crews, 2004; Kampov-Polevoy et al., 2003; Langleben, Busch, O'Brien, & Elman, 2012) and a very recent trial including binge eaters (Goodman et al., 2018) that did apply the usual 5 (sweet taste stimuli) x 5 (replicates) sweet taste test protocol, all reported lower proportions of SLs. Comparably, when the same protocol was exclusively used with healthy participants, the SL phenotype was either less common than (Eiler et al., 2018; Kampov-Polevoy, Tsoi, Zvartau, Neznanov, & Khalitov, 2001; Turner-McGrievy, Tate, Moore, & Popkin, 2013; Turner-McGrievy, Wang, Popkin, & Tate, 2016) or approximately as common as the SD phenotype (Kampov-Polevoy et al., 2014; Kampov-Polevoy, Alterman, Khalitov, & Garbutt, 2006; Kampov-Polevoy, Garbutt, & Khalitov, 2003; Kareken, Dzemidzic, Oberlin, & Eiler, 2013; Lange, Kampov-Polevoy, & Garbutt, 2010; Weafer, Lyon, Hedeker, & de Wit, 2017). Likewise, a study of Polish adolescents using a 3 (sweet taste stimuli) x 1 (replicate) version of the 'highest preference using ratings' method indicated a SL phenotype prevalence of 67%. However, the confounding effect of the well-established enhanced hedonic response to sweet tastes in underage populations (De Graaf & Zandstra, 1999; Garneau, et al., 2018; Mennella, et al., 2014) should also be considered.

3.4 Average liking above mid-point or Positive/Negative average liking classification method (Method 3)

A less commonly reported method of discriminating between the distinct sweet taste liker phenotypes is the 'average liking above mid-point' method or 'positive/negative average liking' method (Table 4). It relies on a dichotomous classification of SLs/SDs analogous to that of the 'highest preference' rating method. However, in this case the discrimination depends on whether the individual average hedonic score ('average liking') for all the presented sweet taste stimuli is higher or lower than a particular cut-off liking value ('mid-

point') or if it is higher or lower than zero when bipolar scales with a zero neutral response are used ('positive/negative'). In some cases, classification in the distinct sweet taste liker phenotypes is established after averaging the liking scores of a single sucrose concentration presented at least twice. In addition, 'mid-point' does not usually refer to one predetermined point at half the distance between the hedonic scales' anchors, but it stands for values ranging from 40 to 60 on a 100-point scale.

Yeomans and colleagues were the first to suggest such a methodological framework for the identification of distinct sweet taste liker phenotypes advocating for a single sweet taste stimulus design based on 0.29 or 0.30 M sucrose (Yeomans, Mobini, Elliman, Walker, & Stevenson, 2006). Except for two studies where the SL phenotype was defined in the inclusion criteria (Mobini, Chambers, & Yeomans, 2007; Yeomans, Leitch, Gould, & Mobini, 2008), the approximate 3:1 ratio of SLs to SDs they reported was comparable with most of the relevant studies (Coldwell, et al., 2009; Yeomans, Prescott, & Gould, 2009; Yeomans, et al., 2007), including a twin cohort of more than 1400 British and Finnish subjects (Tuorila, et al., 2017). Interestingly, the relative proportion of SLs and SDs in these studies was consistent irrespective of the number of different sweet taste stimuli served or the specific cut-off liking scores set in each study. Yeomans & Prescott (2016), who exclusively recruited female subjects, found an even larger number of SLs. In contrast, when comparably small samples were tested, the SL and SD phenotypes were about evenly distributed across participants (Methven, et al., 2016; Sartor et al., 2011; Yeomans, et al., 2006).

3.5 Highest preference via paired comparisons classification method (Method 4)

A rather different approach to distinguish hedonic responses to sweet stimuli is by contrasting the most preferred levels of sweetness for each individual (i.e. based on preferences between stimuli and not on the rated liking for those stimuli). In this protocol developed by researchers at the Monell Chemical Senses Center (Mennella, Lukasewycz, Griffith, & Beauchamp, 2011), sucrose solutions of varying concentrations are presented in a dyadic sequential mode. Participants are forced to point to the solution they "like better"

and each subsequent pair is determined by the preceding preference choice (similar to an adaptive method for taste thresholds). The task continues until the participant chooses the same sucrose concentration relative to both a higher and a lower concentration or the highest or lowest concentration two consecutive times. Participants can then be split into groups which correspond to different sweet taste liker phenotypes depending on the geometric mean of the most preferred concentrations or the number of times a sucrose solution is selected over all the others (i.e. the percentage preference).

Only a few studies which used this sweet-liking assessment protocol then go on to define sweet-liker groups (Table 5). In Grinker's reports the graphical representation of the percentage preference as a function of concentration revealed a group that systematically preferred the lowest sucrose concentration they tasted (two thirds of adults and one third of children tested) and a second group showing either an inverted U-shaped response with optimal preference at 0.18 M (Grinker & Hirsch, 1972) or a monotonically ascending one (Grinker, 1977). A half century later, Mennella and colleagues (Mennella, et al., 2014) also identified two approximately equally distributed sweet taste liker phenotypes after they split a subgroup of their children study population at the median sucrose preference value. Asao and colleagues (Asao, et al., 2015) reported a 3:1 ratio between low and high concentration likers when they compared the geometric mean of the most preferred sucrose concentrations with a concentration threshold they had previously identified via HCA. It is notable that despite large differences in BMI across the adult studies using the 'highest preference via paired comparisons' method, it provided fairly consistent proportions of the SD phenotype.

3.6 Outcome of the different methods compared

Figure 2 shows the sweet-liking data from Tables 1-5 focusing on the weighted average proportions of the different sweet liker phenotypes both within and between the different classification methods. Breaking down the relevant proportion within each method, participants who were classified algorithmically (Method 1b) were approximately evenly distributed between the SL and the SD phenotype (46.3% vs. 45.0%, respectively).

Interestingly, the majority of participants considered SDs in studies using Method 1a and 1b did not actually exhibit strong aversive responses to sweet stimuli, but rather liking for intermediate concentrations (63.8% and 73.5%, respectively). In contrast, studies employing Method 3 identified 63.5% SLs across the total sample, and notably tested younger and leaner subjects, as well as the fewest men as described above (Section 3.1). On the other hand, participants exhibiting erratic responses or presenting no particular preference to any of the sweet stimuli accounted for less than 10% of the population in all methods reviewed here.

When we statistically compared the frequency distributions of the different sweet taste liker phenotypes between methods (Table 7), except Method 4 where, as expected, the disproportionally small number of listed studies led mainly to non-effective contrasts, most of the remaining paired comparisons revealed significant differences in the proportion of SLs between the different phenotyping methods; a similar conclusion was drawn for SDs.

4. DISCUSSION

In reviewing the various approaches used previously to identify sweet taste liker phenotypes, it is clear different methods have evolved out of the specific needs of the set of research questions being addressed, but in doing so the lack of consistency across studies makes it difficult to draw broader strong conclusions on questions such as "is sweet liking associated with higher body weight". It is also clear that all methods have some degree of utility but no single existing method stands without criticism, and for this research area to move forward, there needs to be a more universal adoption of a common method that can quickly identify sweet taste liker phenotypes while minimizing the risks of misclassification. After reviewing the various strengths and weaknesses of existing methods, we propose a way forward that could achieve a more unified approach.

4.1 *Strengths and weaknesses in identifying sweet taste liker phenotypes using different classification methods*

4.1.1 *Interpreting the shape of hedonic response curves (Method 1a & Method 1b)*

The interpretation of individual hedonic response curves was recognized as the most promising of the classification methods currently used. The main argument in favour of this approach is the absence of the need for an arbitrary pre-defined sucrose concentration cut-off value which is an essential element of other methods reviewed here. However, interpreting individual hedonic response curves does not come without its own challenges. A major concern is with the original visual approach, which was based on the interpretation of the individual examining each curve, leading to a risk of subjective or worse yet, unblinded classification of participants. This was particularly an issue when participants deviated from a monotonic response by neither showing linear increases nor decreases in liking ratings as a function of sucrose concentration, or when more than two different patterns of liking curves were evident in the tested sample. Many studies using the visual-interpretation approach tended to classify both participants whose responses had an inverted U-shaped pattern and those who showed descending liking ratings with increasing concentration as a single "negative" group, which potentially conflates two distinct phenotypes for the sake of simplicity. The shape of hedonic response functions also depends on the range of sucrose concentrations being tested, and the lack of a widely accepted concentration range for use in all studies is a major limitation when trying to contrast responses across studies.

The more recent introduction of algorithmic methods and of the agglomerative HCA in particular to interpret hedonic response curves removes most potential bias or inconsistency from visual inspection, and provides an unbiased method to classifying individuals into different sweet taste liker phenotypes. Unlike the visual inspection approach, the steps required for the identification of the distinct groups (clusters) are part of the statistical process. To eliminate the risk of low quality grouping, subsequent to selecting, for example, the agglomerative over the divisive clustering approach, further decisions are left for the researcher to make (Rani & Rohil, 2013). This allows for customization of the steps integrated into the clustering process, such as the selection of the exact linkage method (unweighted pair-group method, maximum or minimum method, Wards' algorithm: Ward, 1963, etc.) and truncation method (manual via incorporating data of the agglomeration schedule into

the dendrogram or automatic determined by inertia or entropy) that best fit with a particular study design (Yim and Ramdeen, 2015). Correspondingly, those specific steps taken along with the relevant line of reasoning warrants to be reported. Robustness of the clusters generated needs to be checked and reported also: split-sample validation (Everitt et al., 2011) or simply contrasting the difference in individual values within a cluster from the cluster mean could be suggested. In addition, as with the visual interpretation method, the outcome of HCA will still be influenced by the concentration range of sucrose solutions used, and limiting this range may lead to misclassification. Moving forward, for direct comparability across different studies, a common range of test stimuli or one common single stimulus is needed. Moreover, unless a prior dataset is already available for a particular cohort and has already been analysed, HCA also requires advanced statistical techniques subsequent to data collection and therefore it is not as viable as, for example, Method 3 as a screening method to quickly identify distinct sweet taste liker phenotypes when that is needed early in a study. Finally, we should note that, "*HCA suffers from the defect that it can never repair what was done in previous steps*" (Kaufman & Rousseeuw, 1990). That is, once a merge or split decision has been executed, no adjustments are possible.

4.1.2 *Highest preference using ratings classification method (Method 2)*

The 'highest preference using ratings' classification method provides a comparatively easy-to-interpret method for discrimination between SLs and SDs. It is noteworthy that this method had the highest consistency in terms of the relative proportions of SL and SD. Considering the most preferred sucrose solution for investigating individual hedonic responses has a precedent in Sensory Science: the forced-choice paired-comparison technique is based on a wider psychophysical approach to determining an individual's most preferred level of a tastant after a series of dyadic contrasts (Meilgaard, Civille, & Carr, 2016; Mennella & Bobowski, 2016).

However, the 'highest preference using ratings' method also has a few clear limitations. First, it uses the liking rating of an arbitrary sucrose concentration (usually 0.83 M) to discriminate SLs from SDs. Kampov-Polevoy and colleagues rationalized this concentration relative to the sucrose content of a commercially available beverage (Coca Cola at 0.33 M).

However, to our knowledge, this choice has not been challenged or justified statistically in any subsequent work. Also, beyond the simple discrepancy (0.83 M versus 0.33 M), a direct comparison between model sucrose solutions and commercial beverages that contain acids, caffeine and aromatic flavors is questionable at best. A further issue is that under their operational definition, anyone who gives the highest rating to the highest concentration of sucrose is classified as SL regardless of the actual valance of their rating for that stimulus. That is, if an individual's highest rating falls below the mid-point of the scale (i.e., below the neutral point), representing an aversive response, they would still be classified as SL. Contrary to the rest of the methods reviewed here, it is also of note that studies using this technique have primarily focused on psychiatric populations (primarily those with alcohol or substance dependence, or other mental health concerns). While this does not invalidate the methodology per se, it does make contrasts of the outcome of studies using that method with other methods more problematic, since these populations are likely to differ from the general population in terms of reward response (Zald & Treadway, 2017).

4.1.3 *Average liking above mid-point or positive/negative average liking classification method (Method 3)*

Concerning the 'average liking above mid-point' or 'positive/negative average liking' method, the relative proportions of SLs and SDs identified by this method was remarkably consistent despite variations in the exact definition of the SL and the SD phenotype between different studies. Still, educated young women made up the majority of participants, and the homogeneity of the population tested may explain the consistency in proportions of SLs and SDs. One clear advantage of this simple method is that it uses only a single test stimulus and so is very quick and easy to administer, which may be the reason it was selected for the largest study reviewed here (Tuorila, et al., 2017).

Nonetheless, the concentration of sucrose used and the specific cut-off points determining which phenotype a participant belongs to remains arbitrary. Another important point is that the 0.29/0.3 M sucrose solution used in many studies is close to the breakpoint concentration of the inverted U-shaped hedonic response curve typically associated with

the SD phenotype (Table 1), suggesting this concentration is possibly too low and risks misclassification errors. Moreover, in studies using the 'average liking above mid-point' or 'positive/negative average liking' method and averaging liking ratings of all stimuli tested, is associated with the large number of low sucrose concentrations included in those sweet taste tests. A high average overall rating that could have resulted from strong liking for low sweetness is interpreted as indicative of the SL phenotype in such studies although it is actually more characteristic of the SD. Indeed, Methven and colleagues highlighted a 16.7% misclassification between this method and the statistically robust interpretation of hedonic response curves (Methven, et al., 2016).

4.1.4 Highest preference via paired comparisons classification method (Method 4)

The sweet-liking assessment protocol associated with the 'highest preference via paired comparisons' approach has been claimed to be a reliable and valid sweet taste test (Mennella & Bobowski, 2016; Mennella, et al., 2011) and the method of choice in pediatric populations (Coldwell et al., 2013) as it allows for cognitive limitations in this population (Guinard, 2000; Mennella, et al., 2011). However, unlike other approaches reviewed here, the paired-comparison approach is a measure of preference which by definition reflects a selection process made within a choice paradigm and not a measure of elicited liking per se (Hayes, 2015). This may be especially subject to experimental and methodological concerns, like adaptation. Indeed, more intense sucrose solutions tend to be preferred in subsequent series within the given task (Leon, Couronne, Marcuz, Köster, & Ko, 1999; Mennella, et al., 2011), in direct contrast to the decreasing liking observed with replicates in other sweet taste test approaches. In addition, in the case of inverted U-shaped response phenotypes where stimuli of diametrically opposed levels of sweetness can be liked or disliked to the same degree, a preference between two items will be forced. On the other hand, a relatively low misclassification rate of 11.5% in favor of the 'low concentration' likers was suggested when Asao and colleagues compared the 'highest preference via paired comparisons' method with the algorithmic interpretation of hedonic curves (Asao, et al., 2015). Likewise, Grinker's sweet taste liker phenotype findings from the 'highest preference via paired comparisons' method were identical to those using the visual interpretation of hedonic curves method

(Grinker, 1977). However, the limited number of studies that have used the 'highest preference via paired comparisons' approach potentially undermines a well-substantiated judgment of this classification method. It could be argued, for instance, that plotting the number of times a solution is selected over all the others as a function of sucrose concentration shares similar subjectivity issues with the visual interpretation of the hedonic curves. Moreover, if the majority of participants prefer the very high or very low sucrose concentrations tested, a subsequent grouping that depends on a median-driven dichotomization could be also problematic.

4.2 *Future directions*

Overall, none of the four classification methods reviewed here is clearly superior to the others. Considering the well-established nature of research into impaired reward system in addicted, depressed, and other psychiatric patients (Zald & Treadway, 2017), continued use of Kampov-Polevoy's original (Kampov-Polevoy et al., 1997) or adjusted (Kampov-Polevoy et al., 2001) sweet taste test protocols (Method 2) for discriminating SL/SD might ensure continuity within this specific research field. However, to overcome the issues we identified with Method 2, a decrease in number of sweet taste test replicates and a liking threshold score to classify SLs are recommended. Regarding Method 4, some would suggest that it could serve as a 'gold standard' approach for the identification of the distinct sweet taste liker phenotypes in pediatric populations (Mennella & Bobowski, 2016; Mennella et al., 2011). Nonetheless, more cognitive demanding sweet taste protocols have been successfully used in both children (Enns et al., 1979; Garneau et al., 2018) and adolescents (Coldwell et al., 2009; Scinska et al., 2001) implying that when the language, attentional, or memory barriers are raised, both underage and adult populations can conceptually collapse to a common classification method.

Those special cases aside, insights gained from this comprehensive methodological review highlight the need for a universally accepted and statistically-founded approach that amalgamates the best aspects of existing approaches into a single reliable method for use in future work. Whether the same approach can be translated to multi-ethnic populations or

participants from different countries remains elusive (Coldwell et al., 2009; Holt et al., 2000; Thai et al., 2011; Tuorila et al., 2017; Turner-McGrievy et al., 2013, 2016), and therefore further exploratory work in this area is necessary. The well-established effect of age on sweet-liking (Bobowski & Mennella, 2017; De Graaf & Zandstra, 1999; Mennella & Bobowski, 2015) along with compelling evidence from the few studies directly contrasting the distribution of sweet taste liker phenotypes in children and adults (Enns et al., 1979; Garneau et al., 2018; Grinker, 1977), frame a clear call for a common but age-specific classification method.

Taking the strengths and weaknesses of the reviewed methods together, we see a strong need for a single large scale study involving multiple sweet stimuli analyzed via HCA to identify the true number of sweet taste liker phenotypes (i.e., binary SL and SD classification, versus 3 or more groupings as seen in recent large studies). Subsequent sensitivity and specificity analysis of such data could facilitate the identification of a single sucrose concentration and associated cut-off values that most reliably allow classification into the appropriate number of phenotypes under a less time-consuming scheme that the use of multiple taste stimuli and/or of sophisticated analysis by most prior methods dictates. Encouragingly, one relatively recent study piloted that (Asao, et al., 2015).

As for the baseline cohort size per se, it is advised to opt for a figure that allows for, at the minimum, the three primary sweet-liking patterns to be identified; that is increasing liking as concentration increases, an initial rise in liking ratings followed by a decline, and descending liking with concentration. The two studies from Korea using HCA (Kim, Prescott, & Kim, 2014, 2017) highlight that more participants do not necessarily reveal the expected sweet-liking patterns if testing conditions lean towards extreme motivational states. Taking collectively the findings from studies using Method 1b into account (Table 2), the robustness of HCA as a grouping method that assists identification of distinct sweet-liking patterns even when subtle differences in liking ratings are observed (Garneau, et al., 2018), a minimum cohort of at least 100 participants is recommended.

With regard to the range of taste stimuli required for the initial analysis, a low concentration at the age-specific sucrose recognition threshold (e.g. in Easterby-Smith, Besford, & Heath, 1994; Kennedy, Law, Methven, Mottram, & Gosney, 2010; Wiriyawattana, Suwonsichon, & Suwonsichon, 2018) or at a concentration just below that level could provide a reasonable

lower extreme. We then recommend a sample set of not less than five to six but no more than nine to ten stimuli (control stimulus, i.e., water, included), with an upper concentration level close to the most broadly used strongest sucrose solutions in the relevant literature (1.0-1.1 M). This would be conducted by incorporating serial dilution principles with a log scale equal spacing approach. Including a stimulus within the most commonly reported sucrose concentration breakpoint range which is associated with the intermediate phenotype (0.2-0.3 M: Tables 1 & 2) would also be recommended. Nonetheless, limiting the use of moderate concentrations that may impede reproducibility of the liking responses (Asao et al., 2015) should be considered. Is then the notion 'less is more' true? The answer depends on counterbalancing the need for adequate individual ratings in order to generate meaningful liking patterns and to enhance reliability of the subsequent sensitivity and specificity checks with the need to minimize fatigue, adaptation (Lawless & Heymann, 2010) and contrast effects (Lim, 2011) multiple-stimuli sweet taste test protocols suffer from.

5. CONCLUSIONS

There remains no consensus on the best method to identify the different sweet taste liker phenotypes: subjective approaches, arbitrary definitions and differences in protocols undermine consistency across prior studies. Considering that sweetness is not uniformly experienced as pleasurable, especially at high concentrations, a better understanding of the individual variations in affective responses to sweetness might shed some light on the complex aspects of human eating behavior and consequently, it may support strategies promoting health and well-being. The development of a statistically robust and less time-consuming and resource-intensive sweet taste liker phenotype discrimination method that enables both the adoption by future studies of some common classification criteria and its application in large epidemiological studies is needed.

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Conflict of Interests

The funding sources had no involvement in the literature search, in the interpretation of findings, in writing the report, or the decision to submit the article for publication. JEH has received speaker fees, travel reimbursements, and/or consulting fees from federal agencies, nonprofit organizations, trade/commodity groups, and corporate clients in the food industry. MRY has received direct research funding from numerous sources including national and international companies, as well as speaker fees, travel reimbursements and consultancy fees from various companies, none of which impact on the work reported here. VI does not have any potential conflicts to disclose.

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Yeomans, M. R., & Prescott, J. (2016). Smelling the goodness: Sniffing as a behavioral measure of learned odor hedonics. *Journal of Experimental Psychology: Animal Learning and Cognition, 42*(4), 391-400. doi: 10.1037/xan0000120

Yeomans, M. R., Prescott, J., & Gould, N. J. (2009). Acquired hedonic and sensory characteristics of odours: Influence of sweet liker and propylthiouracil taster status. *Quarterly Journal of Experimental Psychology, 62*(8), 1648-1664. doi: 10.1080/17470210802557793

Yeomans, M. R., Tepper, B. J., Rietzschel, J., & Prescott, J. (2007). Human hedonic responses to sweetness: Role of taste genetics and anatomy. *Physiology & Behavior, 91*(2-3), 264-273. doi: 10.1016/j.physbeh.2007.03.011

Yim, O., & Ramdeen, K. T. (2015). Hierarchical Cluster Analysis: Comparison of Three Linkage Measures and Application to Psychological Data. *The Quantitative Methods for Psychology, 11*(1), 8-21. doi: 10.20982/tqmp.11.1.p008

Zald, D. H., & Treadway, M. T. (2017). Reward processing, neuroeconomics, and psychopathology. *Annual review of clinical psychology, 13*, 471-495. doi: 10.1146/annurev-clinpsy-032816-044957

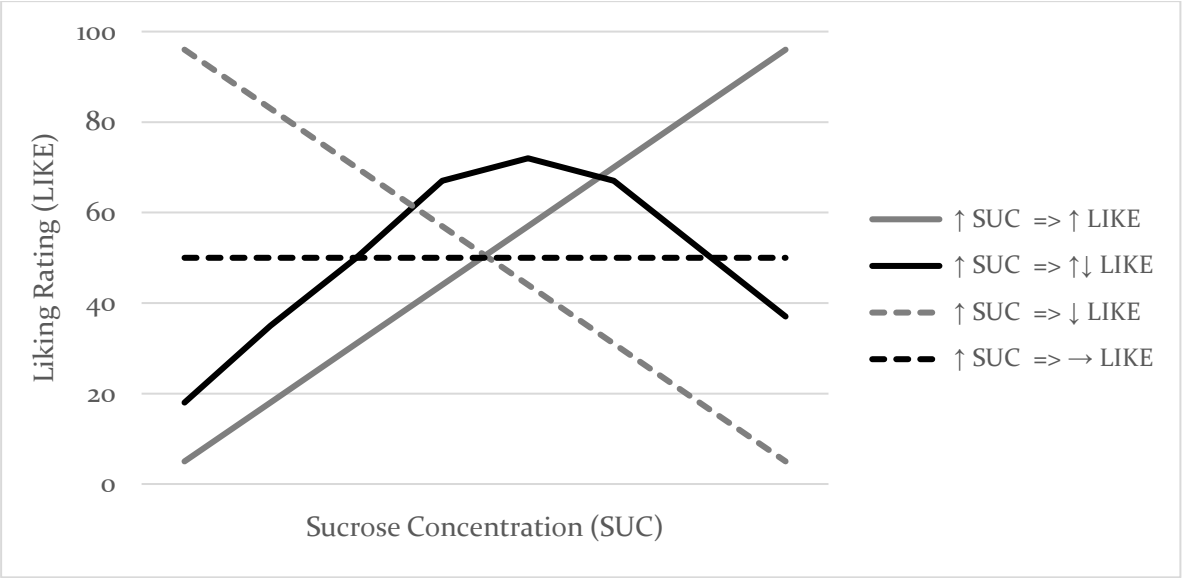

Figure 1. Graphical representation of the most commonly reported sweet taste liker phenotypes as they are illustrated by methods interpreting the shape of hedonic response curves

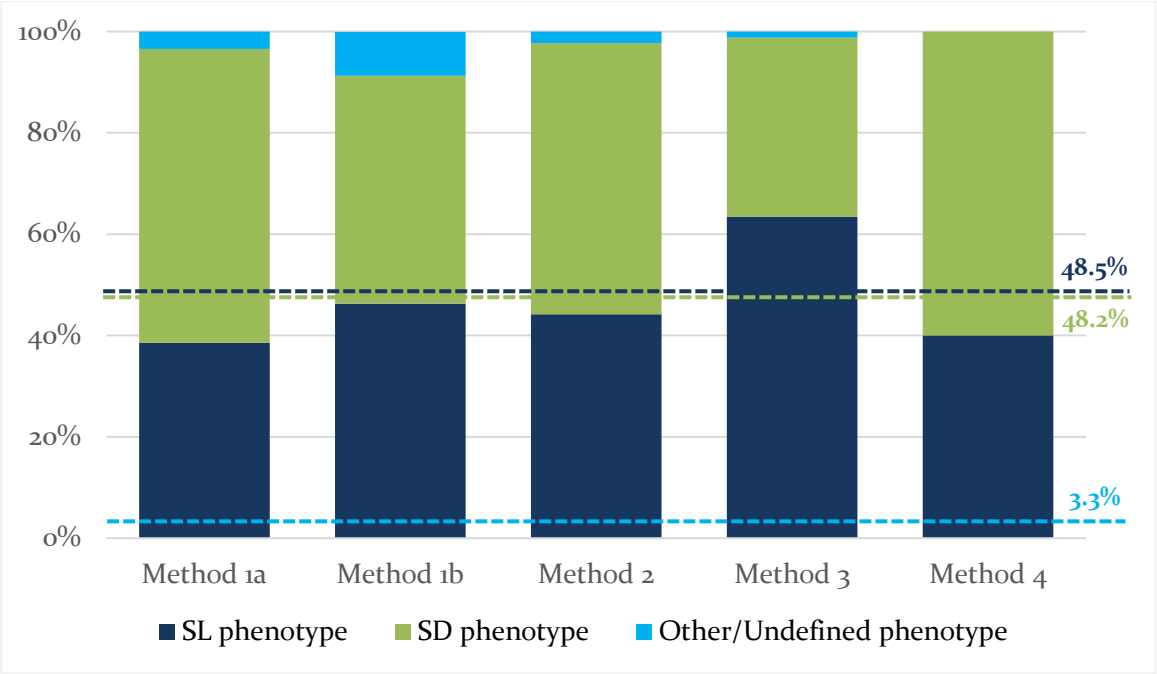

Figure 2. Proportions (%) of sweet taste liker phenotypes by classification method

The dashed lines denote the total weighed average proportions of the different sweet taste liker phenotypes across all methods under review. The dark blue line represents the SL phenotype, the green line represents the SD phenotype, and the light blue line the other/undefined phenotype.

SL, sweet liker; SD, sweet disliker

Method 1a: Visual discrimination of hedonic responses; Method 1b: Statistical discrimination of hedonic responses (algorithmic classification); Method 2: Highest preference using ratings; Method 3: Average liking above mid-point/positive-negative average liking; Method 4: Highest preference via paired comparisons

Table 1. Papers included in this review using the 'Visual discrimination of hedonic responses' classification method (Method 1a) for the identification of the distinct sweet taste liker phenotypes

Author(s), Publication Year	**Country**	**Participants n (% men)**	**Health Status (%)**	**Age in years mean (±s.d.)***	**Sucrose Solutions (x times of replicates)**	**Hedonic Scale**	**Sweet taste liker phenotypes (%)**
Oleson & Murphy (2017)	USA	40 (50)	Healthy (100)	19.0 (1.6)	0.058, 0.12, 0.23, 0.47, and 0.93 M§ (x 2)	gLMS	- High concentration liker (47.5): ↑$_{SUC}$ => ↑$_{LIKE}$ - Moderate concentration liker (52.5): ↑$_{SUC}$ => ↓$_{LIKE}$ or ↑↓$_{LIKE}$, breakpoint at 0.23 M
Eikemo et al. (2016)	Norway	49 (100)	Healthy (100)	24.7 (3.9)	0.05, 0.10, 0.20, 0.42, and 0.65 M (x 3)	VAS	- SL (46.9): ↑$_{SUC}$ => ↑$_{LIKE}$ - SD (53.1): ↑$_{SUC}$ => ↓$_{LIKE}$
Thai et al. (2011) [1]	Malaysia	325 (49)	Healthy (100)	21.0 (14.5)	0.087, 0.22, and 0.55 M§ (x 1)	gLMS	- Type II (48.9): ↑$_{SUC}$ => ↑→$_{LIKE}$ - Type I (51.1): ↑$_{SUC}$ => ↑↓$_{LIKE}$, breakpoint at 0.22 M
Yeomans et al. (2007) (see also Table 4)	UK	60 (33)	Healthy (100)	23.1 (6.2†)	0.05, 0.21, 0.42, and 0.83 M (x 2)	VAS	- SL (66.7): ↑$_{SUC}$ => ↑$_{LIKE}$ - SD (33.3): ↑$_{SUC}$ => ↓$_{LIKE}$ or ↑↓$_{LIKE}$, breakpoint at 0.21 M
Holt et al. (2000)	Australia	132 (42)	Healthy (100)	Australian: 22.8 (4.3) Malaysian: 21.5 (1.2)	0.058, 0.12, 0.23, 0.47, and 0.93 M§ (x 1)	3-point scale	- SL (12.1): ↑$_{SUC}$ => ↑$_{LIKE}$ - SD (87.9): ↑$_{SUC}$ => ↓$_{LIKE}$ *or* ↑↓$_{LIKE}$, breakpoints at 0.12 or 0.23 M
Drewnowski et al. (1998) [2]	USA	121 (0)	Healthy (100)	27.7 (**)	0.058, 0.12, 0.23, 0.47, and 0.93 M (x **)	9-point category scale	- SL (41.3): ↑$_{SUC}$ => ↑$_{LIKE}$ - SD (52.1): ↑$_{SUC}$ => ↓$_{LIKE}$ + 8 participants with undefined sweet taste liker phenotype

Drewnowski et al. (1997)	USA	159 (0)	Healthy (100)	27.0 (8.8††)	0.058, 0.12, 0.23, 0.47, and 0.93 M (x 1)	9-point category scale	- SL (41.5): ↑SUC => ↑→LIKE - SD (51.6): ↑SUC => ↓LIKE *or* ↑↓LIKE, breakpoint at ** + 11 participants with undefined sweet taste liker phenotype
Drewnowski, Henderson, & Shore (1997)	USA	87 (0)	Healthy (100)	25.4 (5.6††)	0.058, 0.12, 0.23, 0.47, and 0.93 M (x 1)	9-point category scale	- SL (34.5): ↑SUC => ↑→LIKE - SD (65.5): ↑SUC => ↓LIKE
Franko et al. (1994)	USA	40 (0)	Bulimia nervosa (38) Bulimia nervosa with history of anorexia (12) Healthy (50)	Bulimia nervosa: 25.0 (4.0) Controls: 24.0 (4.0)	0.039, 0.078, 0.149, 0.30, 0.632, and 1.632 M‡‡ (x 2)	analogue scale	- (37.5): ↑SUC => ↑→LIKE - (50.0): ↑SUC => ↑↓LIKE, breakpoint at 0.078 M - (12.5): ↑SUC => ↓LIKE
Travers et al. (1993)	USA	41 (61)	PD (61) Healthy (39)	PD patients M: 62.4 (5.0) F: 67.8 (8.3) Controls: M: 64.4 (7.8) F: 61.2 (3.8)	0.04 [3], 0.08, 0.15, 0.3, 0.6, 0.9, and 1.5 M (x 1)	6-point category scale	- (36.6): ↑SUC => ↑→LIKE - (63.4): ↑SUC => ↑↓LIKE, breakpoint at 0.3 M

Looy et al. (1992)	Canada	Group 1: 22 (41)	** (**)	**(**)	0.05, 0.10, 0.21, 0.42, and 0.83 M (x 5)	VAS	*Group 1* - SL (40.1): ↑SUC => ↑LIKE - SD (31.8): ↑SUC => ↓LIKE + 6 participants with neutral, inverted U-shaped or erratic response
		Group 2: 38 (29)	** (**)	**(**)			*Group 2* - SL (34.2): ↑SUC => ↑LIKE - SD (36.8): ↑SUC => ↓LIKE + 11 participants with neutral, inverted U-shaped or erratic response
Looy & Weingarten (1992)	Canada	66 (42)	** (**)	20.3 (3.5)	0.05, 0.10, 0.21, 0.42, and 0.83 M (x 8)	VAS	- SL (33.3): ↑SUC => ↑LIKE - SD (50): ↑SUC => ↓LIKE - Neutral (10.6):↑SUC => →LIKE + 4 participants with erratic response
Looy & Weingarten (1991)	Canada	28 (43)	** (**)	20.5 (3.5)	0.03, 0.05, 0.10, 0.16, 0.21, 0.31, 0.42, 0.62, and 0.83 M (x 8)	VAS	- SL (32.2): ↑SUC => ↑LIKE - SD (46.4): ↑SUC => ↓LIKE - Neutral (21.4):↑SUC => →LIKE
Drewnowski & Schwartz (1990)	USA	50 (0)	Healthy (100)	20.2 (1.7)	0.059, 0.24, 0.50, and 1.06 M§§ (x 1)	9-point category scale	- Type II [4] (36.0): ↑SUC => ↑LIKE - Type I [4] (64.0): ↑SUC => ↓LIKE *or* ↑↓LIKE, breakpoint at 0.24 M
Frijters & Rasmussen-Conrad (1982)	NL	25 (0)	Overweight (51) Normal weight (48)	[24-53 years old]	0.06, 0.1148, 0.2089, 0.3082, 0.6918, and 1.3 M (x 3)	3-anchor line (midpoint for the ideal sweetness)	- Type II (4.0): ↑SUC => ↑LIKE - Type I (92.0): ↑SUC => ↑↓LIKE, breakpoint at ** - Neutral (4.0): ↑SUC => →LIKE

Malcolm et al. (1980)	USA	22 (0)	Healthy (100)	[18-40 years old]	0.006 [5], 0.012 [5], 0.03 [5], 0.06 [5], 0.09, 0.15, 0.3, 0.5, 0.8 and 1 M (1 x)	9-point category scale	- Type II (45.5): ↑$_{SUC}$ => ↑→$_{LIKE}$ - Type I (54.5): ↑$_{SUC}$ => ↑↓$_{LIKE}$, breakpoints at 0.3 M and 0.5 M
Johnson et al. (1979)	USA	49 (**)	Obese in weight loss (65)	Behavior modification weight loss: 36.0 (**)	0.058, 0.10, 0.17, 0.32, 0.58, and 1.46 M§ (x 2)	9-point category scale	- Type II (30.6): ↑$_{SUC}$ => ↑$_{LIKE}$ - Type I (69.4): ↑$_{SUC}$ => ↑↓$_{LIKE}$, breakpoints at 0.17 and 0.32 M
				Meal replacement weight loss: 35.0 (**)			
			Normal weight (35)	Controls: 24.0 (**)			
Enns et al. (1979)	USA	Children: 21 (76)	** (**)	Children M: 10.5 (0.2††) W: 10.7 (0.3††)	0.056, 0.1, 0.17, 0.32, 0.56, and 1.0 M (x 3)	9-point category scale	Children: (76.2): ↑$_{SUC}$ => ↑$_{LIKE}$ (23.8): ↑$_{SUC}$ => ↓$_{LIKE}$
		Young adults: 27 (63)	** (**)	Young adults M: 19.0 (1.0††) W: 18.3 (1.6††)			Young adults: (63.0): ↑$_{SUC}$ => ↑$_{LIKE}$ (37.0): ↑$_{SUC}$ => ↑↓$_{LIKE}$, breakpoint at 0.32 M
		Elderly: 12 (42)	** (**)	Elderly M: 71.6 (2.8††) W: 70.5 (3.6††)			Elderly: (41.7): ↑$_{SUC}$ => ↑$_{LIKE}$ (58.3): ↑$_{SUC}$ => ↓$_{LIKE}$
Grinker (1977) [6] (see also Table 5)	USA	56 (34)	Extremely obese (45)	Extremely obese: 34.2 (**)	0.057, 0.10, 0.17, 0.32, and 0.57 M§ (x 1)	9-point category scale	- (30.4): ↑$_{SUC}$ => ↑→ $_{LIKE}$ - (69.6): ↑$_{SUC}$ => ↓$_{LIKE}$

			Moderately obese (25) Normal weight (30)	Moderately obese: 32.7 (**) Normal weight: 23.1 (**)			
Thompson et al. (1977)	USA	32 (**)	Obese (44) Normal weight (56)	20.0 (3.0)	0.075, 0.15, 0.3, 0.6, 0.9, 1.2, and 1.5 M (x 1)	Magnitude estimation method	- Type II (31.2): ↑SUC => ↑LIKE - Type I (68.8): ↑SUC => ↑↓LIKE, breakpoint at 0.6 M
Thompson et al. (1976)	USA	*Group 1* 18 (61) *Group 2* 59 (19)	Normal weight (100) Overweight/ Obese (100)	*Group 1* Type II: 19.6 (1.5) Type I: 19.2 (1.3) *Group 2* Type II: 33.9 (15.9) Type I: 38.3 (13.4)	*Group 1* 0.075, 0.15, 0.3, 0.6, 0.9, 1.2, and 1.5 M *Group 2* 0.06, 0.1, 0.25, 0.4, 0.7, 1.0, and 2.0 M (x 1)	Magnitude estimation method	*Group 1* - Type II (27.8): ↑SUC => ↑→LIKE - Type I (72.2): ↑SUC => ↑↓LIKE, breakpoint at 0.3 M‡ *Group 2* - Type II (35.6): ↑SUC => ↑→LIKE - Type I (64.4): ↑SUC => (↑)↓LIKE, breakpoint at 0.25 M‡
Grinker & Hirsch (1972) [7, 8]	USA	23 (**)	Obese (43) Normal weight (57)	**(**)	0.057, 0.10, 0.18, 0.33, and 0.61 M§§ (x 1)	7-point category scale	- (56.5): ↑SUC => ↑↓LIKE with breakpoint at 0.18 M - (43.5): ↑SUC => ↓LIKE
Pangborn (1970)	USA	29 (100) [8]	** (**)	**(**)	0.023, 0.059, 0.094, 0.13, 0.17, 0.20, and 0.24 M§§‡ (x 5)	9-point category scale	- Like (55.0): ↑SUC => ↑LIKE - Like-dislike (20.0): ↑SUC => ↑↓LIKE, breakpoint at 0.094 M - Dislike (25.0): ↑SUC => ↓LIKE

Notes

*Age mean and s.d. rounded to one decimal place

**No information available

†s.d. calculated from standard error (SE) (SE=s.d./√sample size)

††s.d. calculated from standard error of the mean (SEM) (SEM=s.d./√sample size)

§Sucrose concentration in M (mol/L) calculated from % w/v based on sucrose's molecular weight (342.296 g) and the assumption that the solvent is pure/deionized water at 20°C (Haynes, 2016)

§§Sucrose concentration in M (mol/L) calculated from % w/w based on sucrose's molecular weight (342.296 g) and the assumption that the solvent is pure/deionized water at 20°C (% w/w = % w/v x Special $Gravity_{solution}$) (Haynes, 2016)

‡Based on reviewers' conclusion after interpreting the shape of the hedonic response curves

‡‡Based on reviewers' assumption that the sucrose concentration was initially expressed in % w/w

[1] The between-sex sweet taste liker phenotypes results are presented.

[2] It is not clear whether there is an overlap between participants in the current report (Drewnowski, et al., 1998) and those in Drewnowski et al. (1997b).

[3] Only 28 of the 41 participants tasted and rated the 0.04 M solution.

[4] Type I and II sweet taste liker phenotypes' description is adjusted based on Thompson and colleagues original paper (Thompson, et al., 1976)

[5] The relevant liking ratings weren't included in the sweet taste liker phenotype classification.

[6] It is not clear whether the presented sweet taste liker phenotypes results being were collected before or after the red "cherry" colour manipulation of the sucrose solutions.

[7] Original reference in Grinker, J., Smith, D. V. & Hirsch, J. (1971). Taste preferences in obese and normal weight subjects. *Proceedings of the IVth International Conference on the Regulation of Food and Water Intake*, Cambridge, England (abstract).

[8] It is not clear whether there is an overlap between participants rating stimuli on a hedonic scale (Table 1) or those tested via the paired-comparison technique (Table 5).

[9] Only 20 of the 29 participants completed the entire series of replicates.

$\uparrow_{SUC}$: Increasing sucrose concentration

$\downarrow_{LIKE}$: Descending liking rating

$\uparrow\downarrow_{LIKE}$: Inverted U-shaped hedonic response curve

$\uparrow_{LIKE}$: Ascending liking rating

↑→$_{LIKE}$: Ascending liking rating followed by a plateau

→$_{LIKE}$: Consistent liking rating

AN, anorexia nervosa; BMI, body mass index; gLMS, generalized Labeled Magnitude Scale; liking ratingM, men; NL, The Netherlands; PD, Parkinson disease; SUC, sucrose concentration; s.d., standard deviation; SD, sweet disliker; SL, sweet liker; VAS, Visual Analog Scale; W, women

Table 2. Papers included in this review using the 'Statistical discrimination of hedonic responses' classification method (algorithmic classification: Method 1b) for the identification of the distinct sweet taste liker phenotypes

Author(s), Publication Year	**Country**	**Participants n (% men)**	**Health Status (%)**	**Age in years mean (±s.d.)***	**Sucrose Solutions (x times of replicates)**	**Hedonic Scale**	**Sweet taste liker phenotypes (%)**
Garneau et al. (2018) [1]	USA	Children: 303 (41) Adults: 650 (38[†])	Healthy (**) Unhealthy (**) Healthy (**) Unhealthy (**)	Children: 10.9 (2.2) Adults: 41.8 (16.5)	0.070, 0.13, 0.22, and 0.40 M[§] (x 1)	VAS	*Children* - Cluster 1 -- SL (78.2): ↑$_{SUC}$ => ↑$_{LIKE}$ - Cluster 2 -- SD (21.8): ↑$_{SUC}$ => ↓$_{LIKE}$ *Adults* - Cluster 1 -- SL (33.5): ↑$_{SUC}$ => ↑$_{LIKE}$ - Cluster 2 -- Neutrals (17.7 + 40.3): ↑$_{SUC}$ => ↑↓$_{LIKE}$, breakpoint at ** *and* => →$_{LIKE}$ - Cluster 3 -- SD (8.5): ↑$_{SUC}$ => ↓$_{LIKE}$
Kim et al. (2017)	Republic of Korea	120 (0)	** (**)	24 (**)	0.087, 0.17, 0.35, 0.70, and 1.05 M[§] (x 1)	9-point category scale	- Cluster 4+5 -- SL (32.5): ↑$_{SUC}$ => ↑$_{LIKE}$ - Cluster 1 (35.8): ↑$_{SUC}$ => ↑↓$_{LIKE}$, breakpoint at 0.35 M - Cluster 2+3 -- SD (31.7): ↑$_{SUC}$ => ↓$_{LIKE}$
Methven et al. (2016) (see also Table 4)	UK	36 (34 [2])	** (**)	26 (**)	0.087, 0.17, 0.35, 0.70, and 1.05 M[§] (x 1)	VAS	- Cluster 1 -- SL (36.1):↑$_{SUC}$ => ↑$_{LIKE}$ - Cluster 2 -- SD (63.9): ↑$_{SUC}$ => ↑↓$_{LIKE}$, breakpoint at 0.17 M
Asao et al. (2015) (see also Table 5)	USA	26 (46)	Healthy (100)	32.6 (14.5)	0.035, 0.053, 0.079, 0.118, 0.177, 0.266, 0.399, 0.598, 0.897, and 1.346 M (x 2)	VAS	- Cluster 2 -- High concentration liker (50.0): ↑$_{SUC}$ => ↑$_{LIKE}$ - Cluster 1 -- Low concentration liker (50.0): ↑$_{SUC}$ => ↑↓$_{LIKE}$, breakpoints between 0.118 M-0.266 M

Kim et al. (2014)	Republic of Korea	200 (0)	** (**)	22 (**)	0.087, 0.17, 0.35, 0.70, and 1.05 M§ (x 1)	VAS	- Cluster 1 (49.5): $\uparrow_{SUC}$ => $\uparrow_{LIKE}$ - Cluster 2 (31.5): $\uparrow_{SUC}$ => $\uparrow\downarrow_{LIKE}$, breakpoint at 0.70 M *or* ≈> $\uparrow\rightarrow_{LIKE}$ - Cluster 3 (19.0): $\uparrow_{SUC}$ => $\uparrow\downarrow_{LIKE}$, breakpoint at 0.35 M

Notes

*Age mean and s.d. rounded to one decimal place

**No information available

§Sucrose concentration in M (mol/L) calculated from % w/v based on sucrose's molecular weight (342.296 g) and the assumption that the solvent is pure/deionized water at 20°C (Haynes, 2016)

[1] The paper was available online on the 12th of October 2017.

[2] One participant denied the relevant information.

$\uparrow_{SC}$: Increasing sucrose concentration

$\downarrow_{LIKE}$: Descending liking rating

$\uparrow\downarrow_{LIKE}$: Inverted U-shaped hedonic response curve

$\uparrow_{LIKE}$: Ascending liking rating

$\rightarrow_{LIKE}$: Consistent liking rating

BMI, body mass index; gLMS, general labeled magnitude scale; LIKE, liking rating; SUC, sucrose concentration; s.d., standard deviation; SD, sweet disliker; SL, sweet liker; VAS, visual analog scale

Table 3. Papers included in this review using the 'Highest preference using ratings' classification method (Method 2) for the identification of the distinct sweet taste liker phenotypes

Author(s), Publication Year	Country	Participants n (% men)	Health Status (%)	Age in years mean (±s.d.)*	Sucrose Solutions (x times of replicates)	Hedonic Scale	Sweet taste liker phenotypes (%)
Eiler et al. (2018) [1]	USA	74 (43)	Healthy (100)	22.8 (1.6)	0.05, 0.10, 0.21, 0.42, and 0.83 M (x 3)	**	- SL (35.1): $LIKE_{max}$ at 0.83 M - SD (63.5): $LIKE_{max}$ at 0.05, 0.10, 0.21, or 0.42 M + 1 participant with no available data
Goodman et al. (2018) [2]	USA	41 (15)	Binge-eating disorder (100)	38.0 (11.5)	0.05, 0.10, 0.21, 0.42, and 0.83 M (x 5)	analogue scale	- Highest sweet preferer (43.9): $LIKE_{max}$ at 0.83 M - Other sweet preferer (56.1): $LIKE_{max}$ at 0.05, 0.10, 0.21, or 0.42 M
Weafer et al. (2017)	USA	71 (51 [3])	Healthy (100)	[21-35 years old]	0.05, 0.10, 0.21, 0.42, and 0.83 M (x 5)	VAS	- SL (50.7): $LIKE_{max}$ at 0.83 M - SD (47.9): $LIKE_{max}$ at 0.05, 0.10, 0.21, or 0.42 M + 1 participant with non-appropriate concentration-response curve
Turner-McGrievy et al. (2016)	USA	209 (16)	Obese in weight loss (100)	42.3 (11.0)	0.05, 0.10, 0.21, 0.42, and 0.83 M (x 5)	VAS	- SL (33.5): $LIKE_{max}$ at 0.83 M - SD (66.5): $LIKE_{max}$ at 0.05, 0.10, 0.21, or 0.42 M
Garbutt et al. (2016)	USA	80 (71)	Alcoholic (100)	47.0 (8.6)	0.05, 0.10, 0.21, 0.42, and 0.83 M (x 5)	analogue scale	- SL (27.5): $LIKE_{max}$ at 0.83 M - SD (72.5): $LIKE_{max}$ at 0.05, 0.10, 0.21, or 0.42 M

Swiecicki et al. (2015)	Poland	72 (29)	Depressed with SAD (25) Depressed without SAD (33) Healthy (42)	Depressed with SAD: 36.3 (9.3†) Depressed without SAD: 36.8 (10.3†) Controls: 35.4 (11.5†)	0.029, 0.30, and 0.99 M§§ (x 2)	2-anchor line	- SL (71.0): $LIKE_{max}$ at 0.99 M - SD (29.0‡): $LIKE_{max}$ at 0.029 or 0.30 M
Weafer et al. (2014)	USA	20 (**)	Healthy (100)	[18-30 years old]	0.05, 0.10, 0.21, 0.42, and 0.83 M (x 5)	VAS	- SL (**): $LIKE_{max}$ at 0.83 M - SD (**): $LIKE_{max}$ at 0.05, 0.10, 0.21, or 0.42 M + 1 participant with non-appropriate concentration-response curve
Kampov-Polevoy et al. (2014)	USA	150 (49)	Alcohol use disorders+ (50) Alcohol use disorders- (50)	21.0 (1.8)	0.05, 0.10, 0.21, 0.42, and 0.83 M (x 5)	VAS	- SL (50.0): $LIKE_{max}$ at 0.83 M - SD (50.0): $LIKE_{max}$ at 0.05, 0.10, 0.21, or 0.42 M
Damiano et al. (2014)	USA	57 (88)	ASD (33) Healthy (67)	ASD patients: 26.0 (8.0) Controls: 20.4 (5.6)	0.05, 0.10, 0.21, 0.42, and 0.83 M (x 5)	analogue scale	- SL (49.1): $LIKE_{max}$ at 0.83 M - SD (50.9): $LIKE_{max}$ at 0.05, 0.10, 0.21, or 0.42 M
Kareken et al. (2013)	USA	16 (75)	Healthy (100)	26.1 (4.4)	0.05, 0.10, 0.21, 0.42, and 0.83 M (x 3)	VAS	- SL (50.0): $LIKE_{max}$ at 0.83 M - SD (50.0): $LIKE_{max}$ at 0.05, 0.10, 0.21, or 0.42 M
Sienkiewicz-Jarosz et al. (2013)	Poland	40 (38)	PD (50) Healthy (50)	PD patients: 60.6 (27.7††) Controls: 56.3 (7.2††)	0.029, 0.30, and 0.99 M§§ (x 2)	2-anchor line	- SL (70.0): $LIKE_{max}$ at 0.99 M - SD (30.0‡): $LIKE_{max}$ at 0.029 or 0.30 M

Turner-McGrievy et al. (2013)	USA	196 (16)	Overweight/ Obese (100)	42.6 (11.0)	0.05, 0.10, 0.21, 0.42, and 0.83 M (x 5)	analogue scale	- SL (35.2): $LIKE_{max}$ at 0.83 M - non-SL (64.8‡): **
Langleben et al. (2012)	USA	15 (87)	Opioid-dependent (100)	34.3 (8.2)	0.05, 0.10, 0.21, 0.42, and 0.83 M (x 3)	Likert scale	- SL (33.3): $LIKE_{max}$ at 0.83 M - SD (66.7): $LIKE_{max}$ at 0.05, 0.10, 0.21, or 0.42 M
Dichter et al. (2010)‡‡	USA	31 (**)	Depressed (52) Healthy (48)	Depressed: **(**) Controls: **(**)	0.05, 0.10, 0.21, 0.42, and 0.83 M (x 5)	analogue scale	- SL (12.9): $LIKE_{max}$ at 0.83 M - SD (87.1‡): $LIKE_{max}$ at 0.05, 0.10, 0.21, or 0.42 M
Lange et al. (2010)	USA	158 (39)	Healthy [4] with FHA+ (50) Healthy [4] with FHA- (50)	[20-25 years old]	0.05, 0.10, 0.21, 0.42, and 0.83 M (x 5)	analogue scale	- SL (55.1): $LIKE_{max}$ at 0.83 M - SD (44.9‡): $LIKE_{max}$ at 0.05, 0.10, 0.21, or 0.42 M
Tremblay et al. (2009)	USA	215 (55)	Alcoholic (43) Healthy (57)	Alcoholics: 47.7 (9.1) Controls: 25.9 (6.0)	0.05, 0.10, 0.21, 0.42, and 0.83 M (x 5)	VAS	- SL (40.5): $LIKE_{max}$ at 0.83 M - SD (14.0): $LIKE_{max}$ at 0.05 M + 85 participants with $LIKE_{max}$ at 0.10, 0.21, or 0.42 M + 13 participants with no preference
Swiecicki et al. (2009)	Poland	76 (32)	Depressed (61) Healthy (39)	Depressed: 38.2 (10.9†) Controls: 35.4 (11.5†)	0.029, 0.30, and 0.99 M§§ (x 2)	2-anchor line	- SL (63.2): $LIKE_{max}$ at 0.99 M - SD (36.8‡): $LIKE_{max}$ at 0.029 or 0.30 M
Garbutt et al. (2009)	USA	40 (73)	Alcoholic (100)	49.0 (9.0)	0.05, 0.10, 0.21, 0.42, and 0.83 M (x 5)	analogue scale	- SL (37.5): $LIKE_{max}$ at 0.83 M - SD (62.5): $LIKE_{max}$ at 0.05, 0.10, 0.21, or 0.42 M

Wronski et al. (2006)	Poland	78 (100)	Alcoholic (58) Healthy (42)	Alcoholics: 44.3 (10.1††) Controls: 42.8 (11.5††)	0.029, 0.30, and 0.99 M§§ (x 2)	2-anchor line	- SL (60.3): $LIKE_{max}$ at 0.99 M - SD (**): **
Kampov-Polevoy et al. (2006)	USA	163 (39)	Healthy (100)	22.1 (2.6††)	0.05, 0.10, 0.21, 0.42, and 0.83 M (x 5)	analogue scale	- SL (52.8): $LIKE_{max}$ at 0.83 M - SD (46.0): $LIKE_{max}$ at 0.05, 0.10, 0.21, or 0.42 M + 2 participants with no available data
Krahn et al. (2006)‡‡	USA	65 (100)	Alcoholic (100)	[18-65 years old]	0.05, 0.10, 0.21, 0.42, and 0.83 M (x 5)	VAS	- SL (56.9): LIKEmax at 0.83 M - SD (**): **
Kampov-Polevoy et al. (2004) [5]	USA	165 (49)	Alcohol or drug abuse disorder and/or psychiatric disorder (100)	37.7 (11.6††)	0.05, 0.10, 0.21, 0.42, and 0.83 M (x 5)	analogue scale	- SL (31.5): $LIKE_{max}$ at 0.83 M - SD (68.5‡): $LIKE_{max}$ at 0.05, 0.10, 0.21, or 0.42 M
Kampov-Polevoy, Garbutt, & Khalitov (2003)	USA	163 (39)	Healthy with PHA+ (50) Healthy with PHA- (50)	22.1 (2.6††)	0.05, 0.10, 0.21, 0.42, and 0.83 M (x 5)	analogue scale	- SL (50.9): $LIKE_{max}$ at 0.83 M - SD (49.1‡): $LIKE_{max}$ at 0.05, 0.10, 0.21, or 0.42 M
Kampov-Polevoy et al. (2003)	USA	180 (48)	Alcohol or drug abuse disorder and/or psychiatric disorder (100)	37.7 (12.1††)	0.05, 0.10, 0.21, 0.42, and 0.83 M (x 5)	analogue scale	- SL (31.0 [6]): $LIKE_{max}$ at 0.83 M - SD (69.0 [6]): $LIKE_{max}$ at 0.05, 0.10, 0.21, or 0.42 M

Janowsky et al. (2003)	USA	32 (34)	Cocaine dependent (50) Depressed (50)	Cocaine dependent: 34.6 (6.6) Depressed: 31.7 (9.4)	0.05, 0.10, 0.21, 0.42, and 0.83 M (x 5)	10-point analogue scale	- SL (28.1): LIKEmax at 0.83 M - SD (**): ** + 1 participant with $LIKE_{max}$ at both 0.42 and 0.83 M
Bogucka-Bonikowska et al. (2002)	Poland	60 (100)	Opioid-dependent (47) Healthy (53)	Opioid-dependent: 40.5 (5.9) Controls: 41.3 (9.0)	0.029, 0.29, and 0.87 M§ (x 1)	2-anchor line	- SL (50.0): $LIKE_{max}$ at 0.87 M - SD (**): ** -
Bogucka-Bonikowska et al. (2001)	Poland	62 (100)	Alcoholic (48) Healthy (52)	Alcoholics: 43.6 (8.8††) Controls: 41.3 (8.5††)	0.029, 0.29, and 0.87 M§ (x 1)	2-anchor line	- SL (58.1): $LIKE_{max}$ at 0.87 M - SD (**): **
Kranzler et al. (2001)	USA	122 (48)	Healthy with PHA+ (47) Healthy with PHA- (53)	PHA+: 26.0 (5.8) PHA-: 25.8 (6.1)	0.05, 0.10, 0.21, 0.42, and 0.83 M (x 5)	VAS	- SL (57.4): $LIKE_{max}$ at 0.42 or 0.83 M - SD (17.2): $LIKE_{max}$ at 0.05 or 0.1 M + 25 participants with $LIKE_{max}$ at 0.21 M + 6 participants with no preference
Kampov-Polevoy et al. (2001)‡‡	Russia	57 (100)	Alcoholic (56) Healthy (44)	Alcoholics: 37.6 (7.9††) Controls: 32.0 (9.0††)	0.05, 0.10, 0.21, 0.42, and 0.83 M (x 5)	analogue scale	- SL (31.6): $LIKE_{max}$ at 0.83 M - SD (68.4‡): $LIKE_{max}$ at 0.05, 0.10, 0.21, or 0.42 M
Scinska et al. (2001)	Poland	42 (100)	PHA+ (48) PHA- (52)	PHA+: 15.4 (4.0††) PHA-: 14.0 (3.8††)	0.029, 0.29, and 0.87 M§ (x 1)	2-anchor line	- SL (66.7): $LIKE_{max}$ at 0.87 M - SD (**): ** -

Kampov-Polevoy et al. (1998) [7]	USA	78 (100)	Alcoholic (33) Healthy (67)	Alcoholics: 40.0 (10.4) Controls: 38.8 (10.9)	0.05, 0.10, 0.21, 0.42, and 0.83 M (x 5)	analogue scale	- SL (34.6): $LIKE_{max}$ at 0.83 M - SD (33.3): $LIKE_{max}$ at 0.05 or 0.1 M - + 25 participants with $LIKE_{max}$ at 0.21 or 0.42 M or with no preference ($LIKE_{max}$)‡
Kampov-Polevoy et al. (1997)	USA	57 (100)	Alcoholic (35) Healthy (65)	Alcoholics: 40.1 (10.1) Controls: 38.8 (11.3)	0.05, 0.10, 0.21, 0.42, and 0.83 M (x 5)	analogue scale	- SL (54.4): $LIKE_{max}$ at 0.42 or 0.83 M - SD (38.6): $LIKE_{max}$ at 0.05 or 0.1 M + 4 participants with $LIKE_{max}$ at 0.21 M‡

Notes

*Age mean and s.d. rounded to one decimal place

**No information available

†s.d. calculated from standard error (SE) (SE=s.d./√sample size)

††s.d. calculated from standard error of the mean (SEM) (SEM=s.d./√sample size)

§Sucrose concentration in M (mol/L) calculated from % w/v based on sucrose's molecular weight (342.296 g) and the assumption that the solvent is pure/deionized water at 20°C (Haynes, 2016)

§§Sucrose concentration in M (mol/L) calculated from % w/w based on sucrose's molecular weight (342.296 g) and the assumption that the solvent is pure/deionized water at 20°C (% w/w = % w/v x Special $Gravity_{solution}$) (Haynes, 2016)

‡Based on reviewers' calculation from the sweet taste liker phenotypes' description provided by authors

‡‡Based on participants' baseline data

[1] The paper was available online on the 12th of December 2017.

[2] The paper was available online on the 17th of November 2017.

[3] Data were derived from the 70 participants who were classified as SLs or SDs.

[4] Regardless the current medical problems exclusion criterion, 18.3% of the study sample was later identified as positive to alcohol-related problems.

[5] Sample was derived from Kampov-Polevoy et al. (2003a).

[6] Percentages were calculated based on data from 161 participants with available sweet liking data.

[7] Three quarter of the sample (57 participants) was derived from Kampov-Polevoy et al. (1997).

ASD, autism spectrum disorder; BMI, body mass index; FHA-, negative family history of alcoholism; FHA+, positive family history of alcoholism; LIKE, liking rating; $LIKE_{max}$, maximum liking rating; PD, Parkinson disease; PHA-, negative paternal history of alcoholism; PHA+, positive paternal history of alcoholism; SAD, seasonal affective disorder; s.d., standard deviation; SD, sweet disliker; SL, sweet liker; VAS, visual analog scale

Table 4. Papers included in this review using the 'Average liking above mid-point or positive/negative average liking' classification method (Method 3) for the identification of the distinct Sweet taste liker phenotypes

Author(s), Publication Year	Country	Participants n (% men)	Health Status (%)	Age in years mean (±s.d.)*	Sucrose Solutions (x times of replicates)	Hedonic Scale	Sweet taste liker phenotypes (%)
Tuorila et al. (2017)	UK & Finland	1455 (20)	** (**)	British: [17-82 years old] Finnish: [17-39 years old]	0.58 M§ (x 1)	LAM scale	- Liker (63.6): LIKE > 0 - Non-liker (36.4): LIKE < 0
Yeomans & Prescott (2016)	UK	84 (0)	Healthy (100)	22 (4)	0.29 M§ (x 2)	VAS	- consistent SL (72.6): $LIKE_{Replicate\ 1} > 60$ *and* $LIKE_{Replicate\ 2} > 60$ - consistent SD (27.4): $LIKE_{Replicate\ 1} < 40$ *and* $LIKE_{Replicate\ 2} < 40$
Methven et al. (2016) (see also Table 2)	UK	36 (34 [1])	** (**)	26 (**)	0.087, 0.17, 0.35, 0.70, and 1.05 M§ (x 1)	VAS	- SL (52.8): $LIKE_{t\_mean} > 50$ - SD (47.2): $LIKE_{t\_mean} < 50$
Sartor et al. (2011)	UK	12 (42)	Healthy (100)	26 (6)	0.056, 0.10, 0.18, 0.32, and 1 M (x 1)	gLMS	- Sucrose likers (50.0): LIKE at 1 M > 55 - Sucrose dislikers (50.0): LIKE at 1 M < 55
Yeomans et al. (2009)	UK	92 (17)	Healthy (100) [2]	21 (**)	0.21 and 0.83 M (x 1)	VAS	- SL (59.8): $LIKE_{t\_mean} > 50$ - SD (40.2): $LIKE_{t\_mean} < 50$

Coldwell et al. (2009)	USA	143 (55)	Healthy (100)	13.5 (14.4†)	0.056, 0.1, 0.17, 0.32, 0.56, and 1 M (x 3)	5-point category scale (+ faces from frowning to smiling)	- High preference (61.5): [$LIKE_{mean}$ at 0.56 and 1 M] – [$LIKE_{mean}$ at 0.056 and 0.1 M] > 0 - Low preference (37.1): [$LIKE_{mean}$ at 0.56 and 1 M] – [$LIKE_{mean}$ at 0.056 and 0.1 M] < 0 + 2 participants with [$LIKE_{mean}$ at 0.56 and 1 M] – [$LIKE_{mean}$ at 0.056 and 0.1 M] = 0
Yeomans et al. (2008)	UK	60 (38)	Healthy (100)	23.5 (6.4)	0.30 M§§‡ (x 2)	VAS	- SL (100.0 [3]): $LIKE_{t\_mean} > 55$ - SD (0.0 [3]): **
Yeomans et al. (2007) (see also Table 1)	UK	60 (33)	Healthy (100)	23.1 (6.2†)	0.05, 0.21, 0.42, and 0.83 M (x 2)	gLMS	- SL (68.3): LIKE at 0.42 *and/or* 0.83 M > 0 - SD (31.7): LIKE at 0.42 *and/or* 0.83 M < 0
Mobini et al. (2007)	UK	60 (30)	Healthy (100)	23.5 (6.4)	0.30 M§§‡ (x 2)	2-anchor line	- SL (100.0 [3]): $LIKE_{Replicate\ 1} > 55$ *and* $LIKE_{Replicate\ 2} > 55$ - SD (0.0 [3]): **
Yeomans et al. (2006)	UK	24 (17)	Healthy (100)	22 (**)	0.30 M§§‡ (x 2)	2-anchor line	- SL (50.0): $LIKE_{t\_mean} \geq 60$ - SD (50.0): $LIKE_{t\_mean} \leq 45$

Notes

*Age mean and s.d. rounded to one decimal place

**No information available

†s.d. calculated from standard error (SE) (SE=s.d./√sample size)

§Sucrose concentration in M (mol/L) calculated from % w/v based on sucrose's molecular weight (342.296 g) and the assumption that the solvent is pure/deionized water at 20°C (Haynes, 2016)

§§Sucrose concentration in M (mol/L) calculated from % w/w based on sucrose's molecular weight (342.296 g) and the assumption that the solvent is pure/deionized water at 20°C (% w/w = % w/v x Special $Gravity_{solution}$) (Haynes, 2016)

‡Based on reviewers' assumption that the sucrose concentration was initially expressed in % w/w

[1] One participant denied the relevant information.

[2] Information from personal communication.

[3] The sweet taste test was conducted at screening level.

BMI, body mass index; gLMS, general labeled magnitude scale; LIKE, liking rating; $LIKE_{mean}$, average hedonic score; $LIKE_{t\_mean}$, average hedonic score across all sucrose solutions and replicates; LAM scale, labelled affective magnitude scale; NL, The Netherlands; SC, sucrose concentration; s.d., standard deviation; SD, sweet disliker; SL, sweet liker; VAS, visual analog scale

Table 5. Papers included in this review using the 'Highest preference via paired comparisons' classification method (Method 4) for the identification of the distinct sweet taste liker phenotypes

Author(s), Publication Year	**Country**	**Participants n (% men)**	**Health Status (%)**	**Age in years mean (±s.d.)***	**Sucrose Solutions (x times of replicates)**	**Hedonic Scale**	**Sweet taste liker phenotypes (%)**
Asao et al. (2015) (see also Table 2)	USA	26 (46)	Healthy (100)	32.6 (14.5)	0.035, 0.053, 0.079, 0.118, 0.177, 0.266, 0.399, 0.598, 0.897, and 1.346 M (x 2)	- ††	- High concentration liker (38.5): geometric mean of most preferred SUC at ≥ 0.598 M - Low concentration liker (61.5): geometric mean of most preferred SUC at < 0.598 M
Mennella et al. (2014)	USA	100 (**)	Healthy (100)	Group B: 8.14 (1.8†) Group A: 7.54 (1.9†)	0.088, 0.18, 0.35, 0.70, and 1.05 M§ (x 2)	- ††	- Group B (47.0): geometric mean of most preferred SUC at ≥ 0.609 M - Group A (53.0): geometric mean of most preferred SUC at < 0.609 M
Grinker (1977) [1] (see also Table 1)	USA	56 (34)	Extremely obese (45) Moderately obese (25) Normal weight (30)	Extremely obese: 34.2 (**) Moderately obese: 32.7 (**) Normal weight: 23.1 (**)	0.057, 0.10, 0.17, 0.32, and 0.57 M§ (x 1)	- ††	- (30.4): ↑$_{SUC}$ => ↑ optimal preference with SUC more often preferred at 0.57 M - (69.6): ↑$_{SUC}$ => ↓ optimal preference with SUC more often preferred at 0.057 M
Grinker (1977) [2]	USA	26 (53.8)	Overweight in weight loss (31) Overweight (31) Normal weight (38)	[8-10 years old]	0.057, 0.10, 0.17, 0.32, and 0.57 M§ (**)	- ††	- (69.2): ↑$_{SUC}$ => ↑ optimal preference with SUC more often preferred at 0.57 M - (30.8): ↑ $_{SUC}$ => ↓ optimal preference with SUC more often preferred at 0.10 M

Grinker & Hirsch (1972) [3, 4]	USA	35 (**)	Obese (63) Normal weight (37)	**(**)	0.057, 0.10, 0.18, 0.33, and 0.61 M[§§] (x 1)	- [††]	-	(37.1): ↑$_{SUC}$ => ↑↓ optimal preference with SUC more often preferred at 0.18 M - (62.9): ↑$_{SUC}$ => ↓ optimal preference with SUC more often preferred at 0.057 M

Notes

*Age mean and s.d. rounded to one decimal place

**No information available

[†]s.d. calculated from standard error (SE) (SE=s.d./√sample size)

[††]Sweet-liking calculated via paired-comparison procedure

[§]Sucrose concentration in M (mol/L) calculated from % w/v based on sucrose's molecular weight (342.296 g) and the assumption that the solvent is pure/deionized water at 20°C (Haynes, 2016)

[§§]Sucrose concentration in M (mol/L) calculated from % w/w based on sucrose's molecular weight (342.296 g) and the assumption that the solvent is pure/deionized water at 20°C (% w/w = % w/v x Special Gravity$_{solution}$) (Haynes, 2016)

[1] It is not clear whether the presented sweet taste liker phenotypes results being were collected before or after the red "cherry" colour manipulation of the sucrose solutions.

[2] The presented data are reviewed in Grinker et al. (1977); the original cited paper didn't match.

[3] Original reference in Grinker, J., Smith, D. V. & Hirsch, J. (1971). Taste preferences in obese and normal weight subjects. *Proceedings of the IVth International Conference on the Regulation of Food and Water Intake*, Cambridge, England (abstract).

[4] It is not clear whether there is an overlap between participants tested via the paired-comparison technique (Table 5) and those rating stimuli on a hedonic scale (Table 1).

SUC, sucrose concentration; s.d., standard deviation

Table 6. Z statistics for pairwise comparisons of sex proportions across the different sweet taste liker classifications methods

		Method 1a (*N* = 1290)		**Method 1b** (*N* = 1335)		**Method 2** (*N* = 2591)		**Method 3** (*N* = 1990)		**Method 4** (*N* = 82)	
	% male	***Z***	***p***	***Z***	***p***	***Z***	***p***	***Z***	***p***	***Z***	***p***
Method 1a	35.5	0.00	1.000	**-3.24**	**0.001**	**9.16**	**< 0.001**	**-7.89**	**< 0.001**	0.87	0.384
Method 1b	29.6	**3.24**	**0.001**	0.00	1.000	**12.85**	**< 0.001**	**-4.36**	**< 0.001**	**2.04**	**0.041**
Method 2	51.1	**-9.16**	**< 0.001**	**-12.85**	**< 0.001**	0.00	1.000	**-19.41**	**< 0.001**	-1.93	0.054
Method 3	22.9	**7.89**	**< 0.001**	**4.36**	**< 0.001**	**19.41**	**< 0.001**	0.00	1.000	**3.64**	**< 0.001**
Method 4	40.3	-0.87	0.384	**-2.04**	**0.041**	1.93	0.054	**-3.64**	**< 0.001**	0.00	1.000

Notes

Z, Z-statistic; *p*, *p-value*

Bold text indicates a significant difference with a p-value less than 0.05

Table 7. Z statistics for pairwise comparisons of sweet taste liker phenotypes proportions across the different classifications methods

		Method 1a (*N* = 1371)		**Method 1b** (*N* = 1335)		**Method 2** (*N* = 2283)		**Method 3** (*N* = 1870)		**Method 4** (*N* = 205)	
	N (%)	***Z***	***p***	***Z***	***p***	***Z***	***p***	***Z***	***p***	***Z***	***p***
SL phenotype											
Method 1a	530 (38.6)	0.00	1.000	**4.06**	**< 0.001**	**3.28**	**0.001**	**13.98**	**< 0.001**	0.37	0.711
Method 1b	619 (46.3)	**-4.06**	**< 0.001**	0.00	1.000	-1.27	0.204	**9.63**	**< 0.001**	-1.70	0.089
Method 2	1009 (44.2)	**-3.28**	**0.001**	1.27	0.204	0.00	1.000	**12.38**	**< 0.001**	-1.16	0.246
Method 3	1187 (63.5)	**-13.98**	**< 0.001**	**-9.63**	**< 0.001**	**-12.38**	**< 0.001**	0.00	1.000	**-6.55**	**< 0.001**
Method 4	82 (40.0)	-0.37	0.711	1.70	0.089	1.16	0.246	**6.55**	**< 0.001**	0.00	1.000
SD phenotype											
Method 1a	795 (58.0)	0.00	1.000	**-6.75**	**< 0.001**	**-2.63**	**0.009**	**-12.80**	**< 0.001**	0.55	0.582
Method 1b	601 (45.0)	**6.75**	**< 0.001**	0.00	1.000	**4.94**	**< 0.001**	**-5.52**	**< 0.001**	**-4.00**	**< 0.001**
Method 2	1222 (53.5)	**2.63**	**0.009**	**-4.94**	**< 0.001**	0.00	1.000	**-11.71**	**< 0.001**	1.78	0.075
Method 3	661 (35.3)	**12.80**	**< 0.001**	**5.52**	**< 0.001**	**11.71**	**< 0.001**	0.00	1.000	**6.91**	**< 0.001**
Method 4	123 (60.0)	-0.55	0.582	**4.00**	**< 0.001**	-1.78	0.075	**-6.91**	**< 0.001**	0.00	1.000
Other/Undefined phenotype											
Method 1a	46 (3.4)	0.00	1.000	**5.78**	**< 0.001**	-1.95	0.051	**-4.28**	**< 0.001**	**-2.66**	**0.008**
Method 1b	115 (8.6)	**-5.78**	**< 0.001**	0.00	1.000	**-8.76**	**< 0.001**	**-10.26**	**< 0.001**	**-4.37**	**< 0.001**
Method 2	52 (2.3)	1.95	0.051	**8.76**	**< 0.001**	0.00	1.000	**-2.67**	**0.008**	**-2.18**	**0.029**
Method 3	22 (1.2)	**4.28**	**< 0.001**	**10.26**	**< 0.001**	**2.67**	**0.008**	0.00	1.000	-1.56	0.119
Method 4	0 (0.0)	**2.66**	**0.008**	**4.37**	**< 0.001**	**2.18**	**0.029**	1.56	0.119	0.00	1.000

Notes

Z, Z-statistic; *p*, *p-value*; SD, sweet disliker; SL, sweet liker

Bold text indicates a significant difference with a p-value less than 0.05