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# PERCEPTUAL ATTRIBUTES OF THE TASTE OF SUGARS

## INTRODUCTION

IN TASTE PSYCHOPHYSICS the quality of sweetness is often regarded as a single taste dimension, along with saltiness, sourness and bitterness. Despite their apparent singularity, however, sweet substances differ in "flavor" as can be seen by a simple comparison of sodium saccharin, glucose and sucrose. Saccharin at moderate and high levels produces an undesirable "off-taste," usually bitter, which inheres in the saccharin molecule itself, and is not traced to any measurable impurity (Helgren et al., 1955). Glucose produces a moderate burning or bitter side taste at the back of the mouth (Cameron, 1947), whereas sucrose provides a uniquely acceptable sweet taste, free from the considerable side-tastes that pervade other sweeteners.

The present study was designed to measure the perceptual differences between sugar flavors, and to assess the importance of dimensions besides sweetness as factors that differentiate sugars from each other. Sugars are ideal test materials with which to uncover the more subtle variations in the sweet taste, because virtually all sugars thus far tested psychophysically with the exception of mannose (Moskowitz, 1971) and gentiobiose are primarily sweet, and are not characterized by an overwhelming bitter side taste. [See Cameron (1947) and Moskowitz (1971) for extended bibliographies on sweetness.] The method of multidimensional scaling, which was proposed in a modified version by Shepard (1966) to accommodate nonmetric versions of interpoint distances, provides a simple means by which different perceptual attributes can be uncovered from similarity or dissimilarity judgments for pairs of sugars. The multidimensional analysis is used here in order to generate a sweetness "flavor space" in which distances between points in the space reflect flavor differences between sugars.

## EXPERIMENTAL

### Stimuli

Based upon the results of earlier psychophysical studies with direct magnitude estimation of sweetness (Moskowitz, 1971), four levels of glucose solution were selected as standards: 0.25M, 0.5M, 1.0M and 2.0M. Matching levels of other sugars were then selected on the basis of equal-sweetness matches, according to sweetness functions reported by Moskowitz (1971). These sugars and their concentrations are listed in Table 1. All of the sugars were reagent-grade quality and the water solvent was distilled and deionized (Hydro Service Supply Co., Inc.). The stimulus solutions were prepared 1 wk prior to the experiment, and were frozen at −10°C until the night before use, when they were thawed, and vigorously remixed. In this way, the solutions were maintained free of molds.

### Subjects

Ss were 12 unpaid volunteers from the test platoon of enlisted men at Natick Laboratories. Four of the Ss had had previous experience with the method of magnitude estimation in evaluating taste intensity. Untrained Ss were shown cards with circles of different sizes and asked to assign numbers in proportion to apparent area. Afterwards, all Ss were introduced to the concept of "flavor difference" via the following procedure. They were shown different objects in the room and different colors, and asked to assign magnitude estimates to the degree of apparent dissimilarity of pairs of forms and pairs of colors. When each S showed that he understood the task, he was permitted to begin the experiment.

### Procedure

On each of five days a different series of stimuli were used. On any one day Ss were presented with a series of stimulus pairs on a lazy susan. The solutions were contained in small 3/4-oz paper souffle cups, containing 12–15 ml of solution. In each pair, one stimulus was a reference sugar (either one of the four glucose references, or one of the four fructose references judged to be equally sweet as shown in Table 1). In a single session, S sampled up to 18 pairs of solutions, and required up to 30 min to complete the session. In Experiments 1–4, two different sugar sets were run in the same session (viz. glycerol and sorbitol, arabinose and xylose, maltose and lactose, galactose and sorbose), and each concentration was compared both to its glucose referent of equal sweetness, and to its fructose referent of equal sweetness. In Experiment 5, fructose was compared directly to glucose, and sucrose was compared to its two referents. In each experiment except Experiment 5, two replicate judgments were obtained for each sample. In Experiment 5 four replicate judgments were obtained for each glucose-fructose pair. In all experiments the order of concentrations within a pair was randomized as well as the order of pairs. Rinsing with tap water was required between pairs, but not within a pair. However, S had to wait at least 10 sec between samples.

### Analysis

The median magnitude estimates of "flavor difference" were computed after the size of numbers used by each S was equated to a standard modulus via the process of *modulus normalization* (Moskowitz, 1970). Briefly, the estimate of each S to a common stimulus across all experiments (viz., 1.8M glycerol and 1.0M glucose) was multiplied by a constant so that it came to 10. All the remaining judgments of that S in the session were also multiplied by the normalizing factor. Each S required a separate multiplier in every experiment.

The median data provided estimates of selected "interpoint distances" corresponding to subjective dissimilarity or difference. The computer program MDSCALE, developed by Kruskal and Carmone was used to find a geometrical configuration so that the distances between points reflected their subjective difference. The program MDSCALE sought this best-fitting configuration with a 4,3,2 and 1 dimensional space, where points corresponded to sugars. The analysis was "nonmetric" because the computer program sought a configuration of points so that only the rank order of interpoint distances (rather than their arithmetical value) was preserved. The "badness-of-fit" was minimized by reducing the so-called "stress"

*Table 1—Concentrations used in flavor difference experiments (Molarity)*

| Sugar[a] | Level 1 | Level 2 | Level 3 | Level 4 |
|---|---|---|---|---|
| Glucose | 0.25 | 0.50 | 1.00 | 2.00 |
| Fructose | 0.12 | 0.26 | 0.62 | 3.50 |
| Glycerol | 0.43 | 0.88 | 1.80 | 3.20 |
| Xylose | 0.32 | 0.68 | 1.40 | 2.50 |
| Arabinose | 0.30 | 0.65 | 1.40 | 2.70 |
| Galactose | 0.26 | 0.72 | 1.50 | – |
| Sorbose | 0.18 | 0.45 | 1.15 | 2.50 |
| Sorbitol | 0.37 | 0.78 | 1.51 | 2.80 |
| Sucrose | 0.08 | 0.20 | 0.45 | 0.90 |
| Maltose | 0.25 | 0.50 | 1.00 | 1.90 |
| Lactose | 0.16 | 0.35 | 0.60 | – |

[a]Reference Pair: Level 3 of glycerol and Level 3 of glucose (for modulus normalization)



VAULT

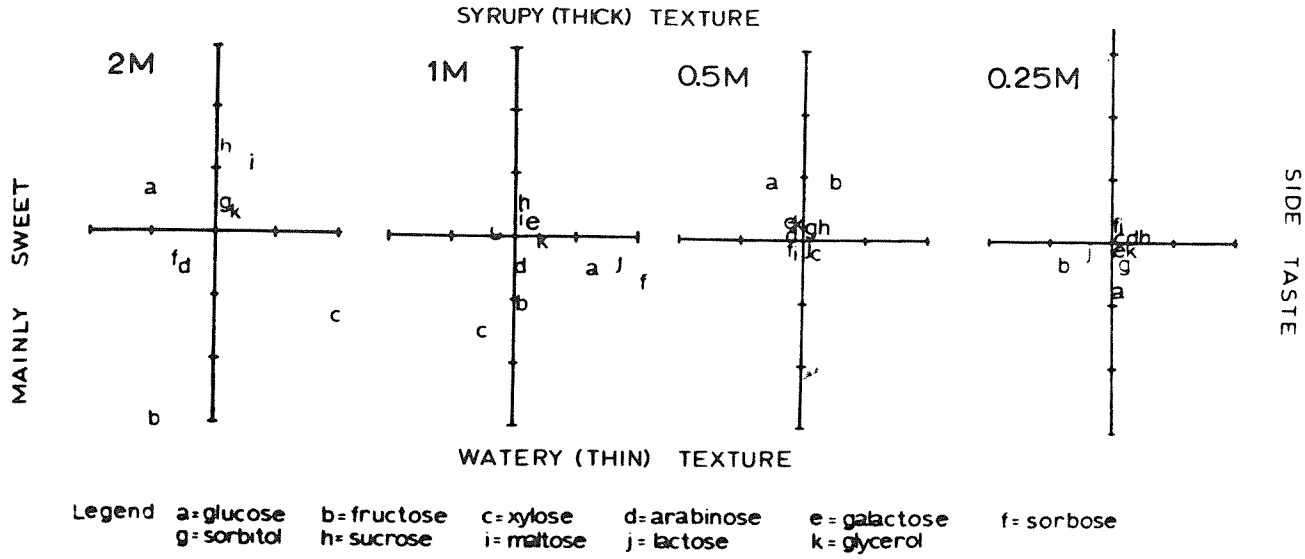


*Fig. 1—The two-dimensional space reflecting the perceptual differences among sugars. Distances between points indicate perceptual differences between sugars based upon nonmetric, multidimensional scaling results. A two dimensional space, comprising the attributes of viscosity and 'side-tastes' adequately accounts for the distances. The map comprises four layers, one for each level of perceived sweetness (equal to that of 0.25M, 0.5M, 1.0M and 2.0M glucose). Each marker represents 1 unit and the map is unique up to a linear transformation. The names of the sugars used and their locations are coded alphabetically by single letters.*

value, and the relation between stress value and dimensionality was a curvilinear, inverse function. As more dimemsions were added, stress decreased in the following way: 1 dimension stress = 0.1524; 2 dimension stress = 0.0086; 3 dimension stress = 0.0091; 4 dimension stress = 0.0093. Because of considerations of parsimony, a two-dimensional configuration of points was selected to economically represent the space of sugar flavor.

## RESULTS

FIGURE 1 presents the two dimensional representation of points that correspond to sugars. Figure 1 is divided into four segments, which each corresponded to the four sweetness levels, equal to the sweetnesses of 0.25M, 0.5M, 1.0M and 2.0M glucose. The entire set of empirical distances (total = 72 interpoint distances) were analyzed together to obtain Figure 1, but the configuration was separated into the four parts shown here.

Based upon the author's tasting of the samples, two appropriate labels may be given to the attributes uncovered by multidimensional analysis: (a) presence vs. absence of side tastes and (b) viscous vs. watery texture. The representation of sugars is slightly confounded by the variability of some points, so that a high concentration of xylose at a sweetness of 2.0M glucose is on one side of the space, towards the region of pronounced side taste, whereas it is primarily sweet at a lower intensity equal to 1.0M. As a general representation, however, the two-dimensional space appears adequate to describe most of the sugars.

*Table 2—Distribution of sugars in two-dimensional space (side taste, viscosity)*

| Level | Standard deviation (glucose-fructose) Side taste | Viscosity | Standard deviation (others)[a] Side taste | Viscosity |
|---|---|---|---|---|
| 1 | 0.61 | 0.31 | 0.17 | 0.03 |
| 2 | 0.10 | 0.71 | 0.11 | 0.09 |
| 3 | 0.80 | 0.37 | 0.75 | 0.82 |
| 4 | 0.33 | 2.68 | 0.85 | 0.93 |

[a]Except glucose, fructose, galactose, lactose

A major finding of this study is that the perceptual differences between moderately and minimally sweet sugars are relatively small, so that the space that they generate is relatively compact. The differences are much greater at the high concentrations, and consequently the space is enlarged. Table 2 presents the standard deviations of the coordinates for all sugars except lactose and galactose. As the sugars increase in sweetness Table 2 shows that the standard deviation of their location coordinates rises on both dimensions, at first slowly, but then drastically with increases in sweetness between 0.5 and 1.0M glucose. The scatter of points is approximately the same for both dimensions.

The coordinates for glucose and fructose were analyzed separately because their placement in the two dimensional space had to satisfy many more interpoint distance constraints than did the remaining sugars (see Table 2). As a consequence, the highest concentration of fructose is placed in an anomalous position at its highest sweetness level (coordinates = 0.700, −3.084 on the two axes, respectively). Such a placement may have been caused by slight inconsistencies among the interpoint distances, so that the anomalous placement is actually "best" in that it minimizes the "badness-of-fit" (stress statistic). Neither lactose nor galactose was sufficiently sweet to match the taste of 2.0M glucose, and these sugars were also eliminated from the computation of variability for the placement of points. Thus, the standard deviation on each axis is comparable across intensities, since the same sugars are represented at each intensity level.

## DISCUSSION

Ss APPEAR CAPABLE of changing their "focus" in sensory evaluation, so that the flavor differences between like-tasting

substances are enhanced by attention to other salient dimensions. For sugars, these dimensions appear to be the attribute of viscosity-fluidity, which is not a taste attribute, and the attribute of "side-tastes." It is quite possible that were the viscosity to be balanced (e.g., by adding sodium carboxy methyl cellulose, a "tasteless" thickener), the perceptual differences among the sugars might diminish considerably, since only one attribute, "side-tastes," would remain. It is also quite possible, however, that the subject possesses a hierarchy of salient attributes, so that equalization for viscosity, and perhaps for "side-tastes" might reveal yet a third and possibly a fourth dimension along which subjects differentiated sugar flavor.

It is instructive to consider the use of evidence presented in Figure 1 as a quantitative indicator about the degree to which sugars can be interchanged in a product. Were all processing properties to remain the same across many sugars, low sweetness products would probably be less sensitive to random interchanges of sugars than high sweetness ones. At the very sweet levels sucrose and sorbitol, as well as glycerol and maltose might be more interchangeable (in this data) than, say, sorbose and arabinose. It should be noted, however, that once attention is paid to a smaller set of sugars for product development the nature of the configuration, as shown in Figure 1 can radically change. Differences between glycerol and sucrose will increase when S pays close attention to them, whereas the differences might be much smaller when glycerol and sucrose are embedded in a much larger set of stimulus sugars.

In order to make the multidimensional scaling of flavor a more useful tool to the food technologist, flavor spaces such as that obtained here, ought to be obtained for specific products, and with appropriate and potentially useful sugars. By that approach, it may well be possible to quantitatively assess the sensory effects to be expected when sugars are substituted for each other in products. The method also promises potential usefulness for the quantification of other taste materials, as well as odors and flavors, which stimulate both taste and smell.

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