The effects of viscosity upon perceived sweetness

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Six concentrations of sucrose and six concentrations of sodium saccharin were presented as stimuli to 30 Ss. The concentrations were equally spaced logarithmically, covering a 32:1 range for each solute. The 12 aqueous solutions were presented at four levels of viscosity, ranging approximately from 1 to 10,000 centipoises, with sodium carboxymethylcellulose (cellulose gum) as the thickening agent. Magnitude estimates indicate that perceived sweetness decreases with viscosity. In log-log coordinates the viscosity-sweetness relation is roughly linear with a negative slope, suggesting that sweetness of both sodium saccharin and sucrose varies as a power function of viscosity, with an exponent between −.20 and −.25.

The viscosity of a substance is one of the many variables that appear to affect taste, although few studies have been made of it. Rather, viscosity has been viewed as a "disturbing secondary criterion" in taste studies (Lewis, 1948), and a *deus ex machina* inserted in the discussion of results by various Es.

Crocker (1945) speculated that the viscosity of a solution thickened with gum tragacanth, flaxseed, or other mucilaginous material interferes with the diffusion of sapid substances to the receptor. Several results from taste threshold studies suggest that this interference occurs in the detection task. In one such study, Mackey and Valassi (1956) showed that sucrose, sodium chloride, caffeine, and tartaric acid were easiest to detect in a liquid solution, intermediate in a foam base, and most difficult in a gel medium. In a later experiment, Mackey (1958) found that when methylcellulose, a common thickener, was added to aqueous solutions of caffeine, quinine, and saccharin, the threshold rose, presumably because of the increased viscosity. Stone and Oliver (1966) also reported that for a number of thickening agents the detection threshold for sucrose was higher than when sucrose was dissolved in water alone.

Stone and Oliver (1966) also investigated the relation between suprathreshold taste intensity and viscosity. They showed that sucrose solutions which had been thickened with various types of natural and artificial gums were rated higher in sweetness than sucrose solutions in pure water. In a similar study, Pangborn (1963) found that in water solutions fructose was rated sweeter than sucrose (on a weight basis), whereas in viscous pear nectar the order was reversed. On the other hand, Skramlik (1926) demonstrated that the intensity of taste was consistently lower in paraffin oil than in water. Thus, there does not appear to be any consensus about the effect of viscosity upon suprathreshold intensity of taste.

The present experiment was designed to determine a functional relation between viscosity and perceived sweetness, and differs from most of the studies cited above in that it attempts to determine this relation in terms of a ratio scale. In addition, it incorporates a larger range of suprathreshold stimuli, and concerns the sweetness-viscosity relation for two different types of sweeteners, sucrose and sodium saccharin, which have different growth functions for perceived sweetness (Stevens, 1969; Moskowitz, 1970b).

PROCEDURE

Subjects

Thirty undergraduate and graduate students served as Ss.

Stimuli

Sodium carboxymethylcellulose ("Cellulose Gum" from Hercules, Inc., 7M and 7H) was used in aqueous solutions of Cambridge tap water to obtain solvent viscosities that were roughly 22x, 484x, and 10,000x normal (approximately equal-logarithmic intervals). Sucrose and cellulose gum were dry mixed before they were mixed with water. The stimuli comprised geometric sequences of sucrose solutions (2% to 64% by weight) and sodium saccharin solutions (.01% to .32% by weight). Adjacent concentrations in the sequence stood in the ratio 2:1. Sucrose solutions of 32% and 64% by weight at 10,000x, and 64% by weight at 484x are missing because they were physically impossible to prepare with a variable speed stirrer (Eastern Industries Model 3). Approximately 3-5 cc of each of the 45 test solutions were presented in small paper cups (¾-oz. Sweetheart souffle cups, No. 039) to the Ss.

Since freshly prepared sucrose solutions taste sweeter because of a higher content of alpha glucose (Cameron, 1947), the sucrose solutions were kept under refrigeration for several days before use in order to allow a mutarotational equilibrium of isomers to be established. Stimuli were served at room temperature (approximately 22°C).

The Ss were given written instructions informing them that their task was to assign a convenient number to the first solution, and to assign numbers to successive solutions in proportion to perceived sweetness. S was told that if he could not detect any sweetness, he should indicate as such, rather than give an arbitrarily small number in place of zero. S was also instructed to ignore both viscosity and side tastes that were not sweet. After S indicated that he understood the isntructions and the procedure of magnitude estimation, he was instructed to sample the first solution, taste it, expectorate, and assign a number proportional to his immediate sensation of sweetness. He was then instructed to rinse with tap water. Each of the 45 solutions was judged once by each S, and the stimuli were presented in a different irregular order to each S.

RESULTS

PSYCHOFIT, a FORTRAN IV program (Panek & Stevens, 1965), was modified in order to analyze the magnitude estimates. Because each S was allowed to choose his own modulus, the program used a normalization procedure known as *modulus equalization* (Lane, Catania, & Stevens, 1961), which left the ratios of the magnitude estimates unchanged, and therefore did not alter the slope of the sensory function in log-log coordinates. Since Ss were occasionally unable to detect any sweetness in some of the solutions, the (postmodulus equalization) medians, rather than the geometric means, were used as the measure of central tendency.

Figure 1 shows the relation between sweetness and the concentrations of both sucrose and sodium saccharin. The resulting straight lines (for log-log coordinates) suggest that the relation is a power function, with the exponent given by the slope of the line. The lowest four concentrations of sucrose across each of the four viscosities approximate straight lines, with slopes ranging between 1.6 and

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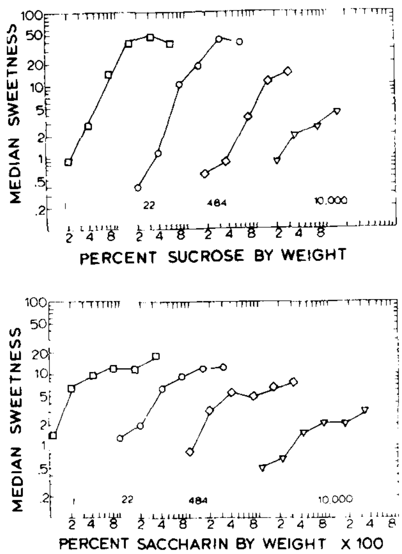

Fig. 1. The relation between concentration and sweetness for sucrose and sodium saccharin. Each sweetener was investigated at four to six concentrations, and under four solvent viscosities (measured in centipoises). The coordinates are log-log, in which straight lines represent power functions relating sweetness to concentration. Pearson r^2 for sucrose sweetness under the four levels of viscosity (in ascending order) is 0.84, 0.89, 0.96, and 0.98, respectively. Pearson r^2 for saccharin sweetness under the four levels of viscosity (in ascending order) is 0.77, 0.88, 0.74, and 0.91, respectively.

2.0. In contrast, the highest two concentrations of sucrose, 32% and 64% by weight, level off–a departure from linearity that has consistently appeared in other studies (Moskowitz, 1968, 1970a, b; Stevens, 1969; Stone & Oliver, 1966). The exponent of the sweetness function for sucrose in log-log coordinates is higher than would be expected from previous studies, but the exponent is relatively constant (to within 20%) across the four log units of viscosity.

In Fig. 1b, where perceived sweetness of sodium saccharin is plotted as a function of the concentration, each of the four functions departs considerably from a straight line, suggesting that the sweetness of this artificial sweetener may not grow as a simple power function of concentration. This departure may be interpreted either as overall curvature or as two straight lines with a knee occurring near the point corresponding to 0.04% sodium saccharin. The difficulties of verifying the latter hypothesis have been discussed by Stevens (1966); since the knee may not occur at the same point for each S, the (averaged) group function will tend to round out the knee. Hence, it may be more profitable to investigate the former hypothesis. One convenient and alternative method for representing the saccharin functions is in semilogarithmic coordinates (where a logarithmic function is rectified into a straight line). The product-moment correlation coefficient between the magnitude estimates and the saccharin concentrations is then appreciably higher than is the case when the data are plotted in log-log coordinates ($r^2 = 0.957$ for 1 centipoise, 0.976 for 22 centipoises, 0.956 for 984 centipoises, and 0.968 for 10,000 centipoises). Presumably, the increasing trend toward linearity for semilog coordinates results from the combination of a low saccharin exponent (at least in some local portions of the function) and overall curvature–which would lead to a logarithmic function as the limiting case.

Figure 2 shows the sweetness of different concentrations of sucrose and saccharin as functions of increasing viscosity. As in Fig. 1, the coordinates are log-log. Each line represents the magnitude estimates given for one concentration across the four levels of viscosity. With the exception of one point for sucrose and three points for sodium saccharin, all 12 functions show that the perceived sweetness of both sucrose and sodium saccharin decreases monotonically with viscosity. Two observations are in order. (1) If a straight line is fitted through the points for each of the six concentrations, the resulting lines have slopes that are nearly parallel, suggesting that the decrease in sweetness caused by increased viscosity is independent of the concentration of sweetener. (2) As a first approximation, the slopes of the lines lie between −.20 and −.25, suggesting that the power function relating perceived sweetness (S) to viscosity (V) is

$$S = kV^n \quad (-.25 \leqslant n \leqslant -.20)$$

where k is a constant that is dependent upon the units used for the variables.

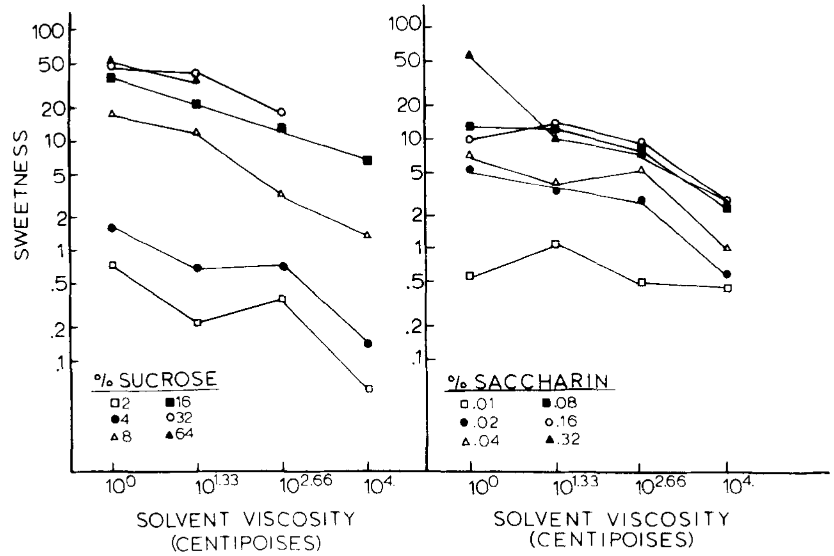

Fig. 2. The relation between viscosity (in centipoises) and sweetness, plotted in log-log coordinates. The parameters are the various concentrations of sucrose and saccharin, which were evaluated at two or more viscosities. The slopes are negative against viscosity, suggesting that increasing the solvent viscosity diminishes sweetness.

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