THE RELATIVE SWEETNESS OF SUGARS: SUCROSE AND DEXTROSE *

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Introduction

The problem of relative sweetness has been attacked by various psychophysical methods. Each of these, however, possesses certain defects which may hinder its effective application. In general the methods may be summed up under two headings: (a) the (absolute) threshold method, and (b) the method of successive comparison. Method *a* has, for various reasons which will become clear in the following discussion, been most frequently applied by investigators in relative sweetness studies.

Using the threshold method Biester, Wood and Wahlin (1) found the lowest concentration of a sugar solution which was perceptibly sweet to a number of subjects. By determining sweetness thresholds for a number of sugars these investigators were able to obtain numerical sweetness ratings. The sweetness of any sugar is taken as the reciprocal of its threshold concentration. The figure thus obtained is then adjusted to sucrose as an arbitrary standard equal to 100 (3). In practice it is simply necessary to divide the sucrose threshold concentration by the threshold concentration of the comparison stimulus and multiply by 100. Numerical ratings for several sweet substances have also been obtained in this manner by Carr, Beck, and Krantz (2) and Willaman (6).

When method *b* is used relative sweetness values may be obtained by dividing the concentration of the sucrose solution used as a standard by the concentration of a solution of the comparison stimulus equivalent in sweetness to the standard. The resultant figure is then multiplied by 100. One should note that relative sweetness is not a term which is operationally equivalent for the two methods. The lack of clarity which had characterized the term relative sweetness should serve to caution workers in this field. If relative sweetness is defined in terms of threshold determinations, one may not quarrel with the definition. On the other hand, the restriction of the term to threshold measurements does not appear particularly fruitful.

The threshold method has the advantage of allowing for rapid determinations since only one point, the threshold, is experimentally determined for each sweet substance. In addition the method avoids the necessity of employing successive comparison which involves responding after a delay to

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one of the comparison stimuli. On the other hand, the use of the method of limits to obtain a threshold has several shortcomings. Concerning these one might point out that thresholds tend to be unstable and difficult to determine with accuracy since they vary from one individual to another and in the same individual from time to time. Further, and perhaps of greater importance, is the fact that the comparison of thresholds can give no reliable information concerning the relative sweetness of supraliminal stimuli. Consequently results based solely upon threshold determinations become misleading when taken to apply over the entire range of stimulus concentrations. One might determine a differential threshold both for sucrose and for any comparison stimulus and use the result as a basis for extrapolation. Such an extrapolation, since it would assume the validity of Weber's Law, appears to be gratuitous and perhaps unjustified. It might also be pointed out that the threshold method does not actually involve the comparison of stimuli. Although the lack of such comparison may not have undesirable consequences, a direct comparison might be more desirable.

Since simultaneous comparison of stimuli is not feasible in taste study, a direct comparison of stimuli entails the use of the method of successive comparison. Biester, Wood, and Wahlin (1) tested the method of successive comparison and took their results to indicate the unreliability of this procedure. They found, for example, that when *S* compares a stimulus in a graded series with one given just prior to it the interval which separates the stimuli must be large if the difference is always to be detected. An interval of 1.5 percent in a sucrose series ranging from 0.75 percent to 9.75 percent gave 94.4 percent accurate judgments. In a galactose series, however, an interval of 4.75 percent was necessary to give 96.2 percent accurate judgments. The authors state that, "In the galactose series three decisions indicated that one solution was as sweet as another having a concentration of 4.75 percent less" (1, p. 390). It is on the basis of such evidence that the method of successive comparison was rejected.

The above conclusion can only be drawn by failure to take into account the differential threshold. Since galactose is only slightly sweet, a small j.n.d. could scarcely be expected. The differential threshold probably assumes considerable importance for studies of relative sweetness. Its significance should not be ignored, and least of all should the existence of a large j.n.d. be so interpreted as to provide a basis for rejecting any method involving successive comparison. Another aspect of the findings of Biester, Wood and Wahlin on the method of successive comparison concerns the error of measurement. Psychophysical measurement like any other measurement shows experimental error. Such error, involving the variability of response, is not eliminated either by using simultaneous comparison or the threshold method.

Willaman (6), using the threshold method, found the sweetness of levulose to be 173 whereas earlier investigations using successive comparison had led to the lower figure of 108. Willaman implies that the discrepancy in results is due to the inaccuracy of tests involving memory. As we have already seen there is no good evidence for such an assumption. Neither is there any a priori reason for assuming that the relative sweetness of a substance can be represented by a single numerical value. Since the threshold method and the method of successive comparison usually involve very different concentrations of the sweet substances, there seems to be no reason for rejecting one sweetness value because of its lack of agreement with another value obtained by another method but at a different concentration. Sweetness values might well be found to vary as a function of the concentration.

Our theoretical argument against the use of taste thresholds and the subsequent attempt to represent relative sweetness by a single numerical value finds support in the work of Renner (5). This investigator found that the relative sweetness of sucrose, glucose and fructose changes with the concentration. He states that the sweetness of glucose is 53 at a concentration of eight percent (sucrose = 100) but rises to 88 at 35 percent. Obviously no single numerical value can adequately represent the relative sweetness of glucose in this instance.

In the light of the above criticisms it appeared justifiable to develop a method adapted to the problem of comparing sweet stimuli regardless of the concentration. Such a method must almost necessarily be a variation of the method of successive comparison. One purpose of the present investigation was to show that the method of successive comparison may be modified to yield reliable results in the determination of relative sweetness. A second purpose was to establish relative sweetness values for two sugars, sucrose and dextrose, over a wide range of concentrations.

Results previously obtained concerning the relative sweetness of dextrose show little agreement. The interpretation of results is complicated by the failure of investigators to use methods which could be expected to render comparable findings or in some cases of authors to specify clearly the method used or the concentrations compared. In other cases investigators have failed to specify the purity of the sugars used. Sometimes one finds dextrose and glucose used as synonymous terms for the relatively pure product dextroglucose while at other times glucose is used to refer to commercial glucose, a mixture of dextroglucose, maltose and dextrins. Such facts explain in part how one investigator arrives at a sweetness value for dextrose of 45 while another reports a value as high as 80.[1]

Subjects, Materials, and Procedure

Five *Ss* were used in the experimental investigation, two male and three female. All were undergraduate college students. Pure sucrose conforming to U.S.P. × 1 was used in all tests. This product contains 99.9 percent sucrose and is 68.1 percent soluble in water at 30° C. Sucrose, or ordinary cane sugar, has apparently a pure sweet taste and it has been used in previous experiments as a standard for the comparison of other sweet substances.

The other sugar used was anhydrous dextrose which is at least 99.5 percent dextrose and

[1] Further references and discussion are given in Biester, Wood and Wahlin (1).

contains not more than 0.5 percent moisture. This conforms to the specifications of the U.S.P. X 1. Dextrose is also known as glucose, grape sugar, or corn sugar. It is slightly less soluble than sucrose, being 54.6 percent soluble in water at 30° C., and in solution it is slightly more fluid than sucrose solutions of equal density. Many higher sugars yield dextrose upon hydrolysis, and dextrose is the form in which nearly all sugar is utilized by the human body.

Soultions of the two sugars were prepared with distilled water and the percentage concentration was determined by the specific gravity method. Occasionally solutions were checked with a refractometer and no discrepancies were noted. Solutions were kept in clean stoppered flasks which were appropriately labeled. New solutions were made up every third day to guard against the formation of molds and subsequent acid production.

Each *S* sat at a small table upon which were placed a 300 cc. beaker containing distilled water for rinsing the mouth and a 600 cc. beaker into which he could expectorate. *Ss* were blindfolded and the nostrils stopped with absorbent cotton. Filter paper cut into strips measuring about one and one-half in. square was used to remove visible moisture from the tongue before each stimulus presentation.

Solutions were placed upon *S*'s tongue with a medicine dropper. The medicine droppers were immersed in distilled water when not in use and were frequently washed with hot water. A possible difference in the size of the drops was not thought to be so great as to produce any appreciable error.

A modification of the method of limits was used in the experimental investigation. A standard sucrose solution was compared with a series of dextrose solutions which ranged from definitely less sweet to definitely sweeter than the standard. Ascending and descending runs were made. In an ascending run *S* compared the least sweet dextrose solution with the standard sucrose and proceeded in discrete steps to the point at which the sucrose and dextrose appeared to be of equal sweetness. In a descending run *S* started with a dextrose solution clearly sweeter than the standard and proceeded down, step by step, until an equality point was reached. Judgments of 'sweeter,' 'less sweet' and 'equal' were allowed. In any series the transition from a judgment of 'less sweet' to 'equal' or 'sweeter,' or from 'sweeter' to 'equal' or 'less sweet' established the equality point for that run. Thus, although three response categories were used, *E* treated the data as though there were only two. Judgments of 'doubtful' necessitated that the trial be repeated. To guard against the possibility of *S*'s responding to the length of the run, *S* was started at different points in the series of dextrose solutions in the various runs. The time error was controlled by presenting the standard first in one-half of the trials and the comparison stimulus first in the other half. The order of presentation was varied in random fashion.

In a psychophysical study of this sort atypical judgments sometimes occur. That is, *S* may call a dextrose solution sweeter than or equal to the standard even though in most judgments he calls it less sweet. In such instances a repetition of the trial was made. If the first atypical response was reversed, the run continued in the normal manner. If, however, the first judgment was repeated, it was allowed to stand as the equality measure for that run.

The following instrustions were given to each *S*:

1. Your task is to compare two sensations of sweetness with regard to intensity. The second of a pair of stimuli will always be compared with the first.

2. When the solution has been placed on the tongue close your mouth and press the tongue forward against the roof of the mouth close to the front teeth. Be as consistent as possible in the execution of this procedure.

3. After your mouth has been rinsed and your tongue dried the first stimulus will be given and you will try to form as distinct an image of the sensation as possible.

4. At the command 'Ready' you will rinse your mouth with water from the beaker held in your right hand. At the next command 'Ready' you will expectorate into the large beaker held in your left hand.

5. Your tongue will again be dried and the second stimulus of the pair will be given. At the command 'Report' you will signify your judgment by tapping on the table with the beaker held in the right hand. If the second stimulus is less sweet than the first, tap once; if the second is sweeter than the first, tap twice; if the two are equal, tap three times. Failure to respond will indicate that you are doubtful.

6. After reporting rinse the mouth without command and expectorate at the command 'Ready.'

7. Do not talk at any time except to answer questions from the experimenter or to ask necessary questions concerning your procedure.

Two separate experiments were carried out. Experiment 1 consisted of three measurements for each *S* relating dextrose to the standard sucrose. The three parts of Experiment 1 are referred to as Series 1, Series 2, and Series 3. In Series 1 a series of dextrose solutions was compared with a standard 10 percent sucrose solution. In Series 2 the sucrose standard was 25 percent and in Series 3 it was 40 percent.[2]

Experiment 2 was designed to determine the sweetness of a sucrose-dextrose mixture by comparing a series of concentrations of the mixture with a standard sucrose solution. This experiment was carried out at only one concentration of the standard with a mixture two-thirds sucrose and one-third dextrose. Results in Experiment 2 were compared with a calculated sweetness value of the mixture based upon the separate sweetness values of sucrose and dextrose

RESULTS—QUALITATIVE

*S*s reported few qualitative differences in the sugars at low concentrations. In Series 3, however, qualitative changes in the taste of dextrose became apparent. All *S*s reported a slightly unpleasant bitterness in dextrose solutions of high concentration at one time or another. The bitterness accompanied an intense sweetness. Sucrose at high concentration showed no similar effects, *S*s describing it as purely sweet. At high concentrations sucrose was uniformly described as pleasant and dextrose as unpleasant. One *S* described dextrose as 'digging into' a given area of the tongue in contrast with the greater spread of sucrose over the tongue. Other investigators have noted qualitative effects with change in the concentration, observing that strong dextrose solutions give rise to burning sensations in the throat (4).

Undoubtedly qualitative changes in dextrose, correlated with a change in concentration, introduce a complicating factor in the experiment which cannot be entirely overlooked.

RESULTS—QUANTITATIVE

Experiment 1

Series 1.—The comparison of a 10 percent sucrose solution with a series of dextrose solutions yielded the results shown in Table I.

TABLE I

DEXTROSE CONCENTRATION EQUIVALENT TO 10 PERCENT SUCROSE AND CORRESPONDING SWEETNESS VALUE OF DEXTROSE

Subjects	Mean (conc. dextrose)	SD	SE_M	Sweetness Value (dextrose)
MS	15.4	2.12	.27	65
MC	15.6	1.72	.22	64
MM	15.3	1.34	.17	65
GS	15.6	1.37	.18	64
GF	15.4	2.14	.27	65
All *S*s	15.5			65

[2] We have followed conventional practice in sugar chemistry of specifying concentration as percent by weight, that is the percent which the weight of sugar is of the total weight of solution.

Dextrose concentrations for the first series as obtained by refractometer readings were 9.5, 10.3, 11.1, 12.0, 12.6, 13.2, 13.8, 14.5, 15.5, 16.0, 16.8, 17.5, 18.1, 18.5, 19.5, 20.0, and 21 percent.

Sweetness values for dextrose are seen to be practically the same for all *S*s. The fact that SD values vary considerably for different *S*s may be taken to mean that discrimination is much keener in one *S* than another or that different *S*s use slightly different methods of judging.

Series 2.—A standard 25 percent sucrose solution was used in all tests in this series. The comparison stimuli were 20, 22, 24, 26, 28, 30, 32, 34, 36, 38, 40, 42, 44, and 46 percent dextrose.[3]

TABLE II

DEXTROSE CONCENTRATION EQUIVALENT TO 25 PERCENT SUCROSE AND CORRESPONDING SWEETNESS VALUE OF DEXTROSE

Subjects	Mean (conc. dextrose)	SD	SE_M	Sweetness Value (dextrose)
MS	35.3	3.13	.40	71
MC	35.4	2.76	.35	71
MM	34.8	2.40	.31	72
GS	36.2	1.68	.22	69
GF	35.9	3.51	.45	70
All *S*s	35.5			71

The results show greater variability than in Series 1, and this might be expected. Discrimination in terms of absolute differences is poorer at the higher ranges, and therefore the SD would be expected to increase as it did for all *S*s. Relative sweetness values for dextrose are higher than in Series 1 for all *S*s, the mean having risen from 65 to 71. This is the first indication that the relative sweetness of dextrose is not the same at all concentrations.

TABLE III

DEXTROSE CONCENTRATION EQUIVALENT TO 40 PERCENT SUCROSE AND CORRESPONDING SWEETNESS VALUE OF DEXTROSE

Subjects	Mean (conc. dextrose)	SD	SE_M	Sweetness Value (dextrose)
MS	48.6	3.21	.41	82
MC	47.9	3.12	.40	83
MM	47.8	2.85	.37	84
GS	48.2	3.11	.40	83
GF	48.2	3.66	.47	83
All *S*s	48.1			83

[3] Since percent intervals cannot be assumed to represent equal sense differences at various concentrations, there is no reason why the same interval should intervene between the solutions of one series and another.

Series 3.—A 40 percent sucrose solution was used as a standard. The comparison stimuli were 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, 52, 53, 54, and 55 percent dextrose.

The agreement of the means from one *S* to another is fairly close considering the high concentration of sugars used. In this case the dextrose series ran as high as its saturation point. The 55 percent dextrose solution had a tendency to crystallize slightly, but this fact did not affect the equality judgments, since the solution lay beyond the equality range.

The sweetness value for dextrose again shows a tendency to rise, the average going from 71 to 83. In this case the tendency may be attributed partly to qualitative changes in the dextrose. The sweetness values for dextrose indicate clearly that there is no single value which can adequately express the sweetness value for this sugar. The sweetness of dextrose as a function of the concentration is apparently quite different from that of sucrose.

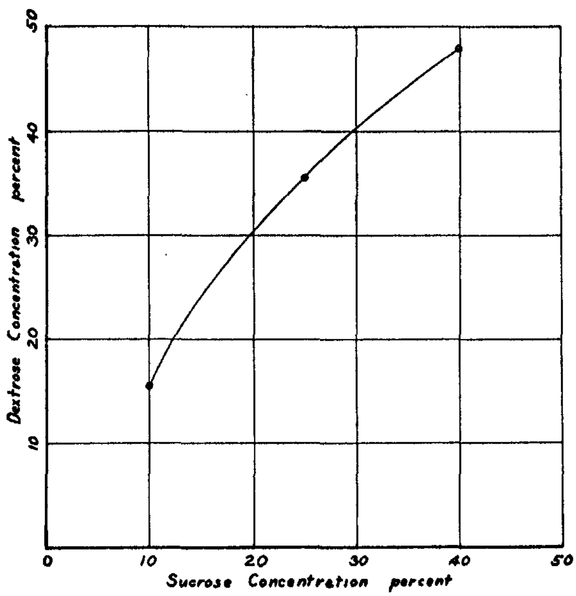

FIG. 1. The concentration of dextrose equivalent in sweetness to sucrose

The SD is again higher in the case of each *S*, indicating poorer sensitivity at the high concentrations used in this series.

Since the distributions of equality judgments in this series are definitely bimodal, SE_M is not a good meausre of reliability. When SE_M was obtained for means of ascending and descending runs taken separately it was found not to exceed .20.

A summary of the results of Experiment 1 is given in Fig. 1.

Experiment 2

A 40 percent sucrose solution was used as a standard. Comparison stimuli were 32, 34, 36, 38, 40, 42, 44, 46, 48, 50, 52, and 54 percent solutions of a two-thirds sucrose, one-third dextrose mixture. Results of this experiment are shown in Table IV.

TABLE IV

SUCROSE-DEXTROSE MIXTURE EQUIVALENT TO 40 PERCENT SUCROSE AND CORRESPONDING SWEETNESS VALUE OF THE MIXTURE

Subjects	Mean (conc. mixture)	SD	SE_M	Sweetness Value (mixture)
MS	42.6	6.32	.81	94
MC	42.7	5.84	.75	94
MM	42.7	5.01	.64	94
GS	42.9	5.31	.68	93
GF	42.6	5.72	.73	94
All *Ss*	42.7			94

One might logically expect that the mixture equivalent to a 40 percent sucrose solution would lie between 40 percent and 48 percent (the latter figure being the dextrose equivalent of a 40 percent sucrose solution as determined by inspection from Fig. 1). Since the mixture is two-thirds sucrose one might expect the concentration of the equivalent mixture to lie nearer the sucrose than the dextrose concentration. By linear interpolation the concentration of the equivalent mixture is found to be 42.68 percent. This agrees very closely with the obtained mean value 42.7. Both the obtained and the calculated equivalent solutions of the mixture have a sweetness value of 94.

SUMMARY

1. A modified method of limits involving successive comparison is found to yield reliable results when applied to the problem of relative sweetness.

2. Sweetness values of dextrose when based upon sucrose as a standard equal to 100 are found to vary with the concentration. At a concentration of sucrose of 10 percent, dextrose has a relative sweetness value of 65. At a concentration of sucrose of 25 percent, the dextrose sweetness value rises to 71 and at a sucrose concentration of 40 percent, dextrose reaches a sweetness value of 83.

3. The relative sweetness of a two-thirds sucrose, one-third dextrose mixture is found to be very close to a value obtained by calculation from the separate sweetness values of the two sugars at a concentration equal to that of the mixture.

4. Qualitative changes in dextrose are apparent at high concentrations. Such changes suggest that sweetness may not be the only taste quality influencing *S*'s judgments.

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