Perceptual changes in taste mixtures

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Three studies were conducted to quantify perceptual changes that occur when sapid chemicals are tasted in mixture solutions. The primary effect when mixing sweetness (glucose or fructose) with salt (NaCl), sour (citric acid), or bitter (quinine sulfate) was to reduce the intensity of each taste in the mixture. The reduction was not equal for the two components, although the overall (total) taste intensity of the mixture appeared to be approximately 50% of the sum of the intensities of the unmixed components. Mixtures of sweet and salt developed an "unblended" or "clashing" taste, in which the components alternated in attempting to dominate the taste percept. Sweet mixed with either sour or bitter blended in almost all proportions. The "flavor" of sweetness in mixtures differed from that of simple sugar sweetness, suggesting that the presence of a second taste modified the qualitative aspect of sweetness. The magnitude of change in sweetness quality depended upon the sugar being rated, and upon the quality and intensity of the second, or modifying, taste.

When sapid chemicals are tasted in a mixture, rather than separately, the mixture taste usually differs from that of its components. The interaction most often noted is a change of gustatory intensity, with most of the experiments indicating a mutually suppressive effect of each component on the other. Previous studies have reported this suppression when a second taste is present at either subthreshold levels (Fabian & Blum, 1943) or at suprathreshold ones (Beebe-Center et al, 1959; Kamen et al, 1962; Pangborn, 1960, 1961, 1962). Sometimes, low levels of NaCl have been reported actually to enhance perceived sweetness (Beebe-Center et al, 1959; Pangborn, 1962), suggesting that more complex taste interactions may occur. Pfaffmann et al (1971) have provided an extensive review of the complicated and often contradictory results in the literature, and have noted that discrepant results may have occurred because of procedural differences in presenting the mixture stimuli.

The "qualitative" dimension of the taste mixture may also differ from that of its components, as was shown by Hambloch and Puschel (1928). In their complicated series of studies they asked Os to report the perceptual qualities for pairs of the four taste "primaries" (salt, sour, sweet, and bitter). They noted several cases in which an intense taste suppressed a weaker one, as might be expected from the other experimental results. When the intensity of the suppressed taste was increased, intensity changes (suppression) still occurred, but the suppressing taste underwent a noticeable change in quality. In a previous study (Moskowitz, 1968, 1971a) several Os reported that mixtures of sour and sweet produced a taste whose quality differed from that of its components, but whose elements (sour and sweet) could be reported on

with appropriate instructions. At that time no attempt was made to pursue a psychophysical investigation of these changes in quality.

In other comments made by Os in the aforementioned paper (Moskowitz, 1968), it appeared that mixtures of sodium chloride and sucrose produced an "unblended" or "clashing" taste, in which each component attempted to assert its dominance in the mixture. A visual analogue of this effect may be seen when narrow blue and red stripes alternate in a two-dimensional pattern. Voluntary reports by Os suggested that the sweet and salt tastes alternated in the mixture and that there was no blending to form a harmonious taste.

The present study concerns the three areas of taste phenomena in mixtures, with the primary goal of obtaining subjective estimates of the perceived intensity of each phenomenon. Where possible, the aim was to develop appropriate predictor equations that could relate the mixture phenomenon to some combination of the component taste intensities.

PROCEDURE

Three separate studies were run, and in each, groups of Os from a pool of

50 gave subjective judgments of the perceived magnitude. In each study stimulus solutions were prepared from reagent-grade chemicals (either Fisher or Sigma Chemical Corp.), mixed on a weight/volume basis with distilled and deionized water. Glucose (dextrose) and fructose were used as the sweet substances, NaCl as the salty stimulus, citric acid as the sour stimulus, and quinine sulfate as the bitter stimulus.

Experiment 1

Intensity of Taste

In Experiment 1 16 Os judged the taste intensity of both simple solutions and mixtures by the technique of magnitude estimation. In three different sessions, glucose and fructose were separately mixed with NaCl, citric acid, and quinine sulfate, respectively. Table 1 presents the arrangement of stimulus concentration. Each stimulus concentration was judged both when in the unmixed state and when mixed with another compound. For all samples, *simple solutions as well as mixtures*, Os were instructed to judge the separate taste intensities of two components (sweet and salty, sour, or bitter, according to the experimental schedule). They were instructed to maintain the same scale for both taste qualities, which permitted subsequent comparisons between simple solutions and mixtures.

Os were instructed to sample the solutions placed before them in small paper cups holding 5-7 ml of solution. They used answer sheets to report the separate taste intensities of the components of each solution. Zeros were used to denote the absence of or both taste qualities in a sample, and the answer sheet was divided into two columns, one for each taste. Os rinsed with tap water between samples, but no fixed time period was maintained between samples. Each trial lasted about 30 sec, including the rinse period, although several Os proceeded more rapidly, whereas others waited for longer periods between sips. Altogether, a total of 47 stimulus samples were evaluated in each session.

Table 1
Concentrations Used (Molarity)

	1	2	3	4	5	6	7
Glucose	.125	.25	.5	1	2		
Fructose	.125	.25	.5	1	2		
NaCl	.03	.06	.125	.25	.5	1	2
NaCl (added to sugar solutions)	.125	.25	.5				
Citric Acid	.00015	.0003	.0006	.00125	.0025	.005	.01
Citric Acid (added to sugar solutions)	.0006	.00125	.0025				
Quinine Sulfate (X 10)	.00015	.0005	.0006	.00125	.0025	.005	.01
Quine Sulfate (X 10) (added to sugar solutions)	.0006	.00125	.0025

Fig. 1. Subjective sweetness of glucose and fructose and subjective saltiness of NaCl, sourness of citric acid, and bitterness of quinine sulfate. The coordinates are log-log and the numerical values for taste intensity are comparable across chemicals.

Os in this study, as well as in Studies 2 and 3 were unpaid volunteer enlisted men at the U.S. Army Natick Laboratories. All had had previous experience in assigning numbers to taste intensity by the method of magnitude estimation.

Because Os were permitted to assign the first stimulus (chosen at random) any convenient positive number, the variability of judgments was inflated by the different sizes of numbers. The technique of *modulus normalization* (Moskowitz, 1970) was used to position the various judgments of different Os on approximately the same numerical scale by an equalization of units (moduli). A computer program (PSYCHOPOWER, Arabie & Moskowitz, unpublished) provided the medians of the judgments, and where appropriate the slope, n , and intercept, k , of the simple power functions, $S = KC^n$, fitted to the median magnitude estimate. Goodness-of-fit was assessed by the Pearson r^2 relating log median judgment (S) to log concentration (C).

In several analyses it proved convenient to fix the exponent of the simple power function at a single representative value for all empirical curves, independent of their actual exponents. Least-squares estimates of the intercept were obtained for each "forced" exponent.

Figure 1 shows the growth curve relating taste intensity to molar concentration for the two sugars and

for salt, sour, and bitter. The coordinates are log-log, and the straight line segments connecting points suggest that curvilinear, rather than linear functions, relate perceived magnitude to physical intensity. For convenience of analysis, however, power functions were fitted to the entire set of data, except where specific points were purposely omitted (e.g., the sourness of citric acid). Power functions fitted to the data have exponents (slopes of the lines in log-log coordinates) that are given in Table 2. Estimated values are 0.97 for NaCl and citric acid, and 0.65 for quinine sulfate. The sourness exponent might be inflated, however, because the lowest concentration falls below the rest of the function considerably. Without considering 0.00015 M citric acid, the sourness function has an exponent here of 0.70 (see Moskowitz, 1971b, for similar sourness exponents for other acids). NaCl also evidences a discrepant lowest concentration, which was not omitted from the computation for slopes and intercepts, since previous results (Moskowitz, 1968, 1971) indicated that the saltiness function for NaCl is curved over the entire range of concentration, in contradistinction to the typical linearity of sourness functions for

acids. The sweetness exponents for glucose and fructose, after pooling the three experiments, are 1.29 and 0.89, respectively.

Comparisons of these exponents, obtained when Os reported on two tastes in the same session, with other studies of mixtures (see Moskowitz, 1968, 1971a) reveal that the exponent is lower than other reports in the literature. Procedural differences might be expected to influence the size of the exponent, with more difficult tasks, such as the present one, introducing "noise" into the sensory function, which might lower the exponent. The primary effect here was to lower the saltiness exponent considerably below the literature value of 1.4 (Ekman & Åkesson, 1964; Moskowitz, 1968; Stevens, 1969); sweetness, sourness, and bitterness obtained exponents that were relatively less depressed.

Because the Os were instructed to assign numbers to taste intensity with the same modulus for the four tastes, the ratios of magnitude estimates at a single concentration across tastes can reflect their relative taste intensities. The five intensity functions were forced to conform to a power function whose exponent was arbitrarily set at 1.3 (although any other common value

Table 2
Parameters of Power Functions $S = KC^n$ Fitted to Simple and Mixture Solutions

Combination	N	K	Pearson r^2	Intercept at $N = 1.3$
1. Glucose	1.16	25.9	0.99	28.5
Glucose + .125 M NaCl	1.36	21.2	0.92	20.7
Glucose + .25 M NaCl	1.74	15.9	0.99	15.9
Glucose + .5 M NaCl	1.45	5.9	0.99	6.2
2. Glucose	1.59	31.3	0.92	28.2
Glucose + .0006 M Citric Acid	1.02	33.2	0.99	33.0
Glucose + .00125 M Citric Acid	0.95	28.4	0.95	28.4
Glucose + .0025 M Citric Acid	1.40	20.9	0.86	20.9
3. Glucose	1.50	27.6	0.90	27.6
Glucose + .00006 M QSO ₄ *	1.32	19.7	0.99	19.6
Glucose + .000125 M QSO ₄ *	1.68	19.3	0.99	19.2
Glucose + .00025 M QSO ₄ *	3.0	6.5	—	11.6
4. Glucose (averaged across three experiments)	1.29	32.24	0.92	32.4
5. Fructose	1.00	40.6	0.94	50.0
Fructose + .125 M NaCl	1.30	23.2	0.98	23.2
Fructose + .25 M NaCl	0.91	9.0	0.75	9.0
Fructose + .5 M NaCl	1.08	11.2	—	10.4
6. Fructose	1.15	41.5	0.99	43.8
Fructose + .0006 M Citric Acid	1.32	39.6	0.96	39.2
Fructose + .00125 M Citric Acid	1.07	41.5	0.89	44.8
Fructose + .0025 M Citric Acid	2.14	15.8	0.99	15.8
7. Fructose	0.70	33.2	0.97	41.2
Fructose + .00006 M QSO ₄ *	1.16	25.6	0.97	26.8
Fructose + .000125 M QSO ₄ *	1.16	17.4	0.77	17.4
Fructose + .00025 M QSO ₄ *	—	20.0	—	—
8. Fructose (averaged across three experiments)	0.89	36.7	0.92	45.91
9. NaCl	0.97	2.14	0.91	194.1
10. Citric Acid	0.97	10 ^{4.09}	0.95	91193.3
11. Quinine Sulfate	0.65	10 ^{4.00}	0.88	10 ^{6.43}

*Quinine Sulfate

Fig. 2. Subjective sweetness of glucose and fructose as a function of molarity. The parameter of each function is the concentration of NaCl, citric acid, or quinine sulfate held constant across varying sugar concentrations. The coordinates are log-log. Stimuli in mixtures that did not taste sweet are not shown.

could have been equally reasonable for this purpose). The result is a set of parallel functions, whose relative separations in logarithmic coordinates are constant, and therefore whose relative taste intensities are forced to remain at a constant ratio. Table 2 shows the intercept values for each material. One molecule of fructose is approximately 1.5 to 2.0 times sweeter than glucose, confirming previous estimates based upon a similar analysis, but with a larger group of sugars (Moskowitz, 1971c). A molecule of sodium chloride appears to be several times more intense than one of sugar, whereas molecules of citric acid and of quinine sulfate exceed sugar sweetness by several orders of magnitude. The exponent 1.3 was selected to make the present analysis comparable to similar computations for the sweetness of sugars (Moskowitz, 1970). The ratios of taste intensities across substances change with the selection of different exponents, but the present values give some idea of the relative taste intensities produced by each material.

Figure 2 presents the subjective sweetness functions, with the parameter of each function being the concentration of the second taste material held constant in either the glucose or fructose solution. Again the coordinates are log-log, and the functions are connected by line segments. Table 2 presents the summary parameters of each function. The lowest concentrations of several sweetness functions are not shown, since the presence of side tastes effectively masked sweetness at low levels. In addition, a number of simple sweetness functions also lack the lowest concentrations, even though from previous studies (Moskowitz, 1970, 1971c) these concentrations were demonstrably above threshold. In particular, 0.125 and 0.25 M sugar solutions were often reported as not tasting sweet. It is quite possible that Os set a criterion of high intensity to report sweetness, especially here, where they had to report the intensity and presence of either one or two tastes.

The slopes of the functions appear

to be only slightly distorted by the addition of separate taste materials (see Moskowitz, 1971a, for comparative slope changes in mixtures). On occasion, however, some severe changes occurred in the exponent, particularly in the presence of high amounts of the second taste material. An insufficient number of concentrations are available to determine (even as a first approximation) whether the marked departures in exponent are representative, or whether they occur because of too few points and possible masking effects that selectively affected the more dilute concentrations of sugar. Previous experiments with mixtures (Moskowitz, 1971a) demonstrated somewhat greater variability in the mean judgments (around the sensory function) when sweetness judgments were made to mixtures of sucrose with other materials. The second taste material may thus add to the "noise" about a sensory function, but would not disguise the underlying function should sufficient numbers of concentrations be investigated.

Figure 3 illustrates how the intercept value for sweetness changes as increasing concentrations of another taste substance are added. An exponent of 1.3 was arbitrarily selected to fit all the functions; any other common value would have been equally correct except that with a 1.3 exponent the sweetness values can be compared directly to previous studies of sweetness (Moskowitz, 1971c). The slopes are not parallel, either for both sugars across the three substances or within a single sugar. NaCl had the greatest effect upon sweetness, since successive 2:1 increments of the NaCl concentration in sugar solution decreased perceived sweetness more than did corresponding increments either of citric acid or of quinine sulfate. Further experiments are in order to ascertain the equation that might fit the functions in Fig. 3. In addition, it is not clear whether the slopes of the functions depend simply upon concentration or upon the subjective saltiness, sourness, or bitterness.

The mixture data were analyzed to determine predictor relations between simple taste intensities and the intensities in a mixture. Only mixtures containing suprathreshold levels of sweetness and the second taste were further considered. Two general forms of equations were examined: (1) equations in which the overall intensity of the mixture was related to some interacting effect of the components on each other and (2) equations in which the overall intensity of the mixture was related to noninteracting effects of the

Fig. 3. The relation between the sweetness of 1.0 molar sugar solution and the concentration of a second material in solution. Four levels of the added substance were studied (0, low, medium, high) corresponding to 0.125, 0.25, and 0.5 M NaCl; 0.0006, 0.00125, and 0.0025 M citric acid; and 0.00006, 0.000125, 0.00025 M quinine sulfate. The abscissa and originates are logarithmic, except for the "0" level, which is placed on the abscissa at the space that would be normally occupied by 0.5 x the value for "low."

components. Eqs. 1-8 below list the five types of equations investigated.

$$S_m = k_1 S_s + k_2 Y_s \quad (1)$$

$$Y_m = k_3 S_s + k_4 Y_s \quad (2)$$

$$S_m = S_s + k_5 Y_s \quad (3)$$

$$Y_m = Y_s + k_6 S_s \quad (4)$$

$$S_m = S_s (10^{k_7 Y_s}) \quad (5)$$

$$Y_m = Y_s (10^{k_8 S_s}) \quad (6)$$

$$S_m + Y_m = k_9 S_s + k_{10} Y_s \quad (7)$$

$$S_m + Y_m = k_{11} (S_s + Y_s) \quad (8)$$

[S = sweetness, Y = other taste intensity (salty, sour, or bitter), s = subjective intensity in unmixed simple solution, m = intensity in mixture solution]. The predictor Eqs. 1, 2, 7, and 8 illustrate mutual suppression, wherein the intensity of both components of a mixture is affected. Eqs. 3, 4, 5, and 6 illustrate a noninteractive suppression.

Out of a total of 15 mixtures each of NaCl, citric acid, and quinine sulfate with either glucose or fructose, only the following number were used in finding the coefficients for Eqs. 1-8: (a) glucose, NaCl (9); (b) fructose, NaCl (9); (c) glucose, citric acid (6); (d) fructose, citric acid (6); (e) glucose, quinine sulfate (5); (f) fructose, quinine sulfate (2).

Each of the eight equations was fitted to the empirical judgments of intensity with the multiple regression program, BMD02R (Dixon, 1967). The equations were analyzed separately for each sugar and then

again for the two sugars together. The coefficients in Table 3 represent the latter analysis, where the data for glucose and fructose were pooled to provide a greater number of cases. Goodness-of-fit was assessed by the arbitrary criterion of a Pearson r^2 exceeding 0.90, a reasonable value when it is recalled that there are no more than 18 observations for any single equation.

Table 3 presents the parameters of the various regression equations, as well as the multiple Pearson r^2 . Equations 1, 2, 7, and 8 provided the best fitting functions in all three cases, suggesting that mixture equations must account for the effect of mutual suppression. Equation 8 is particularly attractive, for it parsimoniously represents the mixture data, with only one free parameter. It suggests that in a mixture in which both tastes are still present, the overall intensity (obtained by adding the components) is some constant proportion of the starting

intensities of the unmixed components. That constant proportion (to within a 15% deviation) may be around 0.50, although there is variation across sugars, as well as across the type of material added.

Pfaffmann et al (1971) have presented another relation between the sum of taste intensities for unmixed sucrose and salt solutions and the taste intensity of the mixture. They reanalyzed mixture data gathered by Beebe-Center et al (1959) and determined the number of gusts (a unit of taste intensity) in simple and mixture solutions. From those values, the following equation may be constructed:

$\log(\text{gusts in mixture})$

$$= 0.6 \log(\text{sum of gusts}$$

$$- \text{simple solutions}) + 0.28 \quad (9)$$

Equation 9 differs from the linear functions suggested by the results obtained here, but also implies an overall reduction of the intensities within a mixture. On the other hand, the reduction follows a power function, so that the constant percentage reduction (40%) occurs for the logarithmic value of the gusts, rather than a 40% reduction for the gusts themselves. No adequate suggestion or hypothesis can be made as yet about the failure of Eq. 9 to pass through the origin (in log-log coordinates).

Experiment 2

The "Clashing" of Tastes

Sixteen Os were instructed to judge the degree to which mixtures of tastes studied in Experiment 1 appeared to "blend together" or to "clash" with each other. All stimuli used in Experiment 1 were evaluated in Experiment 2, with the exception of the unmixed solutions of glucose, fructose, NaCl, citric acid, and quinine sulfate. Because "clashing" and

Table 3
Coefficients of Mixture Equations*

Coefficient	Sweet-Salty	Sweet-Sour	Sweet-Bitter
k_1	0.78	0.80	0.68
k_2	-0.23 (0.83)	-0.14 (0.96)	-0.07 (0.83)
k_3	0.66	-0.18	0.26
k_4	0.03 (0.89)	0.47 (0.85)	0.11 (0.58)
k_5	-0.38 (0.77)	-0.37 (0.74)	-0.29 (0.57)
k_6	-0.34 (0.45)	-0.54 (0.85)	-0.70 (0.28)
k_7	-0.007 (0.78)	-0.007 (0.57)	-0.007 (0.28)
k_8	-0.003 (0.40)	-0.016 (0.83)	-0.014 (0.57)
k_9	0.81	0.60	0.80
k_{10}	0.42 (0.90)	0.33 (0.97)	0.19 (0.97)
k_{11}	0.59 (0.90)	0.49 (0.97)	0.46 (0.94)

*Numbers in parentheses represent the Pearson r^2 between predicted intensity and obtained intensity.

"blending" are not typical dimensions, additional examples from color combinations were required to illustrate the concept. Blue and red, for example, when seen together in alternating stripes, were used as an example of clashing. Yellow and brown stripes were used to illustrate "blending." The order of concentrations was irregular, and each O selected a modulus that was most convenient. No time limits were placed on the O, who was permitted to ask E for clarification of the concept of "clashing" if he felt unsure of that dimension.

The median judgments were computed, and mixtures in which more than 50% of the Os reported a "clash" of tastes were further analyzed to see if an equation could be fitted to the data. Only mixtures of sugar with NaCl produced the required 50% of nonzero judgments; mixtures of sugar with citric acid and with quinine sulfate produced blended tastes according to Os' estimates.

Several different combinations of the intensities of the unmixed components were used to predict the magnitude of the "clashing" effect of sweetness and saltiness. These included the ratio of sweetness to saltiness, their difference (in absolute value), and the logarithms of both of the foregoing values. These four combinations were paired either with the median judgment or with the logarithm of the median judgment.

An r^2 exceeding 0.5 was assumed to represent a moderately good first approximation for this perceptual function.

The best-fitting equation appeared to be

"Clashing"

$$= 0.18 | \text{sweetness} - \text{saltiness} | + 8.06$$

(10)

The multiple regression program (BMD02R, Dixon, 1967) was used to compute the coefficients that provided the "best-fitting" values. The obtained r^2 was 0.52.

Figure 4 presents the plot of the relation between the absolute difference of sweetness and saltiness in the mixture (intensities having been computed for the unmixed solution of each component) and the perceived intensity of "clashing." The points are sufficiently scattered about the regression line to indicate that the function described by Eq. 7 is at best a rough guess. Many Os reported that the assessment of this perceptual dimension was exceedingly difficult, and therefore, Fig. 4 may contain a simple underlying function

confounded by a great deal of "noise."

Prior to the computation of Eq. 7, the initial hypothesis was that the regression line would have a negative slope, with the property that the greatest magnitude of "clashing" would occur when the psychological levels of sweetness and of saltiness were equal. The "clashing" phenomenon would, in turn, be reduced as the separation of intensities increased. That hypothesis was not confirmed, since the slope turned out to be positive.

Experiment 3 The Measurement of "Flavor Difference"

Two months after the completion of Experiments 1 and 2, a new group of 12 Os participated in a study in which they were presented with pairs of solutions, and asked to give numbers in proportion to "how different the flavors were in the two solutions." That is, Os made magnitude estimates of "psychological distance" or of "psychological difference." In each pair, one solution was a reference concentration either of glucose or of fructose (at one of four levels: 0.125, 0.25, 0.5, or 1.0 M). The other solution was a mixture of glucose or fructose with NaCl, citric acid, or quinine sulfate. The levels of the latter three chemicals were maintained at one of the three levels studied in Experiments 1 and 2. The concentrations of glucose and fructose in the mixture were increased to offset the reduction in sweetness that occurred in the mixture. The functions represented in Fig. 2 were used to determine approximate changes in sugar content of a mixture in order to make the sweetness of the mixture equal that of the reference simple solution.

Each O sampled the reference and mixture solutions in quick succession, without rinsing between them, and judged the degree to which the sweetness of the mixture differed in quality from the sweetness of the unmixed reference. The order of solutions within a pair of mixture and reference was changed in a predetermined manner, so that half the time Os sampled the reference first and half the time they sampled the mixture first. The magnitude estimates were normalized by modulus equalization, and plotted in log-log coordinates as a function of the reference molarity. The parameter of each function was the molarity of the second material introduced into the solution. Medians were used as the measure of central tendency.

Figure 5 presents the relation between the molarity of glucose or fructose as the reference sugar and the

Fig. 4. The relation between the absolute difference in subjective sweetness and saltiness for mixture components, and the degree to which these mixtures "clash." The abscissa values were obtained from estimates of the taste magnitudes of the components when those components were evaluated in unmixed solutions. The straight line drawn through the points represents an initial estimate of the best fitting function, and the points are partitioned into three major areas, shown by the enclosing rectangles.

degree to which a mixture of those sugars with NaCl, citric acid, or quinine sulfate differed in sweetness quality from the reference. No standard was presented in the three different sessions (in which NaCl, citric acid, and quinine sulfate were separately evaluated in mixtures) so that the numerical values of the judgements cannot be compared across the three different qualities. The effects of these three chemicals on glucose and fructose can, however, be compared since the two sugars were evaluated in the same session.

Only in a few instances can straight lines be fitted to more than two points in Fig. 5. The selection of more appropriate measures of the independent variable for the continuum of "flavor change" appears to be the next step in quantifying differences in flavor. The empirical results shown in Fig. 5 may not necessarily be described by a single family of functions. The patterns for one sugar do not resemble those for another, and the effects of different chemicals upon a single sugar differ considerably. On the other hand, Os appeared to be capable of making numerical judgments about the degree to which flavors in a mixture were altered, but further studies are needed to refine the technique, and to obtain more substantial information about the functions that Os generate in this task.

CONCLUSIONS AND DIRECTIONS FOR FUTURE RESEARCH

The presence of two separate tastes in solution produces an array of

Fig. 5. The relation between the reference level of a sugar (glucose or fructose) and the degree to which a mixture of glucose or fructose with another substance appears to differ in *sweetness quality* from that of the reference sugar. Open markers represent glucose, and filled markers represent fructose. The mixtures were prepared with NaCl, citric acid, or quinine sulfate, and for each mixture Os were asked to assign numbers in proportion to the difference in "flavor" between the mixture and its unmixed referent. The coordinates are log-log, and the parameter is the amount of the nonsweet substance in the mixture solution. Numerical values are comparable between glucose and fructose for each mixture, although not comparable for the same sugar across the three different materials used in mixtures (NaCl, citric acid, quinine sulfate).

phenomena that are more complex than simple decrements (or increments) in taste intensity. The measurement of suppression in mixtures is, perhaps, the most straightforward and amenable to quantitative study.

The more complex relations between the component intensities in a mixture and the strength of a "clashing" or "unblended" taste are harder to assess, although here Os reported on the strength of "clashing" in salt-sweet mixtures. The future course of work may require a more exacting specification of the independent variables that predict the strength of "clashing." The present variables, chosen as ratios or differences of component (unmixed) intensities, are only one possible set of variables. The nature of the tastes present in solution must also be considered, as well as whether or not

mixtures clash at all, or perhaps only in some intensity levels.

Assessments of "flavor difference" appear to be the most difficult judgments to make, although again Os were aware that mixtures differed in flavor from unmixed references. Prior to determining appropriate predictors of this effect, it would appear to be most valuable to improve the language of taste and smell in order to verbalize the nuances in flavor. The improvement might, in the long run, disclose to psychophysics new areas in the chemical senses that are amenable to measurement, and that can be predicted and controlled by appropriate manipulations of the stimulus variables.

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