The Relative Perception of Weak Sucrose-Citric Acid Mixtures

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SUMMARY

The perception of changes in the relative intensity of sweetness and acidity was investigated with series of sucrose-citric acid mixtures at near-threshold intensities—up to 2% sucrose and up to .0885% citric acid. Changes in citric acid concentration were generally perceived by some tasters to increase sweetness and by other tasters to decrease sweetness. Similarly, changes in sucrose concentration increased or decreased perceived acidity. It is suggested that contradictions between this and previous studies might be due to differences in procedure, which could affect the relative perception of taste intensities. Perceptual processes play as great a part in determining responses to very weak tastes as do the stimuli themselves. Controls and measures of tasters' prior relevant behavior are suggested to be necessary for proper interpretation of their responses.

INTRODUCTION

Recent studies by Kamen *et al.* (1961) and Pangborn (1960, 1962), following Fabian and Blum (1943), have cited apparently contradictory evidence concerning the effects of the presence of citric acid on the perceived sweetness of a sucrose-citric acid mixture. The citric acid may make the mixture more (Kamen *et al.*, 1961) or less (Pangborn, 1960) sweet than a sucrose solution of comparable concentration. Pangborn (1962) has given evidence that the effect of one component on the perceived intensity of the other in a taste mixture depends in some consistent but unexplained manner on the method of presentation used; the methods of paired comparisons and single-stimulus intensity ratings have both been employed, yielding different results for the stimuli of weaker intensity.

This paper reports an experiment designed to investigate some effects that might be considered to modify the perception of weak sucrose-citric acid mixtures, and thus suggest what might be controlled experimentally in order to reconcile divergent findings. The experiment is concerned solely with near-threshold stimulus intensities, and differences between them. In this study, unlike any previous reported work of which we are aware, ratings of relative intensities on both real and imaginary differences between two stimuli were sought. Previous work may therefore be comparable with our findings only where the method is similar.

THEORY

We wish to try to relate the problem of the perception of taste mixtures to precedents that have extensive experimental support in the literature of perception in other senses. To this end we cite, and define formally in the context of the perception of taste mixtures, two sorts of behavior that may arise in responding to complex stimuli. These theories are not original to this paper but are being advanced here in order to derive corollaries that make predictions about the perception of taste mixtures when such mixtures are compared in series.

CONCORDANT RESPONDING

Given a complex stimulus made up of a set of component stimuli each at some measurable intensity, and a measure of intensity that permits comparison between components, such a mixture may have a gestalt quality recognized by a common

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name. For example, a mixture of appropriate intensities of salt, sugar, and tannin in water apparently tastes like sherry to some judges. If the mixture is perceived as a gestalt, then small changes in intensity of one component relative to the rest will not be noticed, because they will tend to be assimilated into the whole pattern of sensations by a process called "closure" (Koffka, 1935). In formal terms, if a_i is the intensity of the *i*th component, and a_j the intensity of some other *j*th component, then if we take all possible ratios of the intensities of two components from the total number of components (in the example of the imitation sherry, three components and three ratios) then the matrix

$$|| \, a_i \, a_j^{-1} \, ||$$

which is the matrix of all such ratios, remains (as perceived) unchanged.

For convenience we will call this "concordant" responding. The corollary to this theory is that a small increase or decrease in concentration of acid added to sucrose should respectively increase or decrease perceived sweetness provided the previous experience of the taster has led him to have an expectation of the balance of relative intensities of components appropriate to the mixture in question: such an expectation may be reinforced by giving the mixture a name, say "lemonade" (Carmichael *et al.*, 1932).

CONTRASTING RESPONDING

An alternative theory, after Helson (1959), is that the subject has a subjective average level of intensity that he uses as a reference against which to judge the intensity of any other stimulus. The subjective average is termed the adaptation level (A.L.) and is postulated to be the geometric mean of the different relevant stimuli to which the subject has previously been exposed. In the case of a taste mixture followed by a taste mixture, A.L. is formally

$$\left(\prod_{i=1}^{n} a_j \right)^{\frac{1}{n}}$$

for a mixture with n components, and on this theory a real small change in intensity of the *i*th component, which we may write as δa_i, results in a perceived change in the other, actually unchanged, components in the opposite direction, which for the *j*th component we may write as $-\delta_j$, because the tasters' A.L. has been moved by the real change δ_i, and the other components are now judged from a new reference level, from which they appear less intense. On this theory we move the A.L. every time we expose the subject to a new different mixture. A crucial test of the theory demands a quantification of the subjective magnitudes of the intensities concerned.

The corollary to this theory assumes that subjects can break down the gestalt quality of the sucrose-citric acid mixture and experience it as a mixture of two parts. This leads to what we will call "contrasting" responses; a small increase or decrease in concentration of acid added to sucrose should respectively decrease or increase perceived sweetness, again provided the previous experience of the taster has been such that he has formed an A.L. The term "contrast effect" has been used in a similar sense by Kamenetzky (1959) to refer to hedonic judgments.

In both the above paradigms the effects of acid on sucrose and sucrose on acid are postulated to be symmetrical.

EXPERIMENT

The object of the experiment was to investigate whether judgments of the apparent direction of intensity change over two successive tastings of the constant-intensity component of a sucrose-citric acid mixture were concordant with or contrasting to real changes in the intensity of the other component present, over the same successive tastings. The design of the experiment also made possible responses indicating that neither concordant nor contrasting effects were occurring for a given taster. The mixtures chosen were tap-water solutions of sucrose and citric acid. Three intensities of each component were involved in the experimental design: $A_1 = .0440\%$, $A_2 = .0625\%$, and $A_3 = .0885\%$ citric acid, and $S_1 = .5\%$, $S_2 = 1.0\%$, and $S_3 = 2.0\%$ sucrose. Only four mixtures of the nine possible were employed, $a = A_2 \, S_1$, $b = A_2 \, S_3$, $c = A_1 \, S_2$, and $d = A_3 \, S_2$. (This notation is used throughout the tables.) The mixtures were tasted in runs of five stimuli, and length of run was chosen as long enough to establish subjective expectancies but at the same time not so long as to induce fatigue or loss of motivation in the taster. The design of the experiment was chosen to reflect the sequential character of most taste experiences, which in the normal consumption situation are the basis of comparative judgments.

There are eight basic runs of five stimuli; the complete paradigm is included in Table 1. The runs designated E1 to E8 correspond to: E1) acid held constant at middle intensity and sucrose increased on the last stimulus, i.e., *aaaab*; E2) the same with sucrose decreased on the last stimulus, i.e., *bbbba*; E3) the same with sucrose increased on the penultimate stimulus and then decreased; i.e., *aaaba*; E4) the same with sucrose decreased on the penultimate stimulus and then increased, i.e., *bbbab*; and E5 to E8) all these four paradigms again but with the roles of citric acid and sucrose interchanged; i.e., with *c* for *a* and *d* for *b*.

In the notation of the tables we have used capital letters to mean sucrose or acid in the case of mixtures, and sweetness or acidity in the case of responses to those mixtures, number suffixes refer to component intensities as chemically defined; lower-case letter suffixes to mixtures as perceived and rated. For example, $S_{3.1}$ is to be read "Sucrose at level S_3 presented after sucrose at level S_1," whereas $A_{a.b}$ is to be read "the acidity of mixture *a* judged relative to the acidity of mixture *b*." Hence, columns headed, say, $S_{c.c}$ or $A_{b.b}$ are comparisons of two identical mixtures tasted one immediately after the other.

For each experimental run there was also a corresponding control run, using the same stimulus

Table 1. Each value in the table is based on 14 responses in the scale range + 3 to − 3.[a]

		Stimuli involved in comparisons			
		1st + 2nd	2nd + 3rd	3rd + 4th	4th + 5th
		Comparisons in sequence			
Run	Variable	1st	2nd	3rd	4th
E1	Stimulus	$(A_2 S_1) = a$	$(A_2 S_1)$	$(A_2 S_1)$	$(A_2)\ S_{3.1}$
	judgment	$A_{a.a}$	$A_{a.a}$	$A_{a.a}$	$A_{b.a}$
	judgment mean	1.00	0.50	0.36	0.14
	judgment s.d.	1.20	1.84	1.76	2.53
E2	Stimulus	$(A_2 S_3) = b$	$(A_2 S_3)$	$(A_2 S_3)$	$(A_2)\ S_{1.3}$
	judgment	$A_{b.b}$	$A_{b.b}$	$A_{b.b}$	$A_{a.b}$
	judgment mean	−0.14	0.21	−0.79	−0.57
	judgment s.d.	1.30	1.26	1.32	2.58
E3	Stimulus	$(A_2 S_1) = a$	$(A_2 S_1)$	$(A_2)\ S_{3.1}$	$(A_2)\ S_{1.3}$
	judgment	$A_{a.a}$	$A_{a.a}$	$A_{b.a}$	$A_{a.b}$
	judgment mean	0.57	0.43	0.36	0.43
	judgment s.d.	1.18	1.40	2.52	2.44
E4	Stimulus	$(A_2 S_3) = b$	$(A_2 S_3)$	$(A_2)\ S_{1.3}$	$(A_2)\ S_{3.1}$
	judgment	$A_{b.b}$	$A_{b.b}$	$A_{a.b}$	$A_{b.a}$
	judgment mean	0.36	−0.29	−0.21	1.07
	judgment s.d.	1.95	1.58	2.34	1.98
E5	Stimulus	$(A_1 S_2) = c$	$(A_1 S_2)$	$(A_1 S_2)$	$(S_2)\ A_{3.1}$
	judgment	$S_{c.c}$	$S_{c.c}$	$S_{c.c}$	$S_{d.c}$
	judgment mean	0.29	0.57	−0.36	−0.29
	judgment s.d.	1.58	1.55	2.12	2.60
E6	Stimulus	$(A_3 S_2) = d$	$(A_3 S_2)$	$(A_3 S_2)$	$(S_2)\ A_{1.3}$
	judgment	$S_{d.d}$	$S_{d.d}$	$S_{d.d}$	$S_{c.d}$
	judgment mean	−0.43	−0.71	0	−0.57
	judgment s.d.	2.19	1.62	2.04	2.19
E7	Stimulus	$(A_1 S_2) = c$	$(A_1 S_2)$	$(S_2)\ A_{3.1}$	$(S_2)\ A_{1.3}$
	judgment	$S_{c.c}$	$S_{c.c}$	$S_{d.c}$	$S_{c.d}$
	judgment mean	−0.07	−0.93	−1.21	0.14
	judgment s.d.	1.98	1.49	2.21	2.29
E8	Stimulus	$(A_3 S_2) = d$	$(A_3 S_2)$	$(S_2)\ A_{1.3}$	$(S_2)\ A_{3.1}$
	judgment	$S_{d.d}$	$S_{d.d}$	$S_{c.d}$	$S_{d.c}$
	judgment mean	−0.71	0	−0.71	0.21
	judgment s.d.	1.44	1.73	1.83	2.24

[a] The stimulus components constant over a given comparison are shown in parentheses.

sequence, but the control-group subjects were asked to make judgments of the component that in fact varied on the last or last two comparisons, whereas the experimental-group subjects judged the relative intensity of the component that in fact stayed constant over the series. It is necessary for the controls to taste the whole stimulus series and not just the comparisons between the two actually different stimuli, because of time-error effects in the series (Borak, 1922).

Each subject did two runs in sequence, and the runs were paired in the design so that the eight run combinations: *E*1 then *E*3, *E*3 then *E*1, *E*2 then *E*4, *E*4 then *E*2, *E*5 then *E*7, *E*7 then *E*5, *E*6 then *E*8, and *E*8 then *E*6 occurred equally often. The total number of subjects was 72, 16 controls and 56 experimentals, which gives four replications of each stimulus run in the controls and fourteen replications of each stimulus run in the experimentals. The subjects were factory and office staff: both sexes and a wide age range were represented, and probably a fair range of intelligence as inferred from their occupations and behavior in previous experiments of varying complexity. They also varied in their experience of food-tasting experiments, but the majority of such experiments in which they had participated were not concerned with psychophysical research.

The intensities of the sucrose and citric acid were chosen on the basis of previous experiments on absolute taste thresholds, some results of which are reported in Gregson (1962), and were intended to represent 2, 3½, and 5 jnd units above absolute threshold estimates for the population of tasters from which the 72 were drawn.

Samples were made in concentrated form and allowed to stand for about ½ hr after dilution to tasting concentrations on the day of use, but were always used within a day of making. Each subject started each tasting run with a tap-water mouth rinse. All tasting was performed individually in closed ventilated tasting cubicles, about 6-ft.-side cubes, the experimenter administering samples via a hatchway and rotary table. Subjects did the runs at their own pace. Illumination was daylight or daylight supplemented by artificial light via "daylight" color filter. Stimuli were colorless liquids in clear-glass tumblers; each portion was about 30 cc.

PROCEDURE

The samples were set before the subject, and the following instructions given: "Here are five samples of a diluted lemon drink. They vary in their sweetness (acidity) and I want you to say how each varies compared to the one you tasted before, using this card." (A card was shown, bearing seven statements as follows: MORE SWEET (+3), SLIGHTLY MORE SWEET (+2), VERY SLIGHTLY MORE SWEET (+1), THE SAME AS THE LAST (0), VERY SLIGHTLY LESS SWEET (−1), SLIGHTLY LESS SWEET (−2), LESS SWEET (−3). The word "sweet" was changed to "acid" where required. The numerical values indicated were never shown to subjects, but were used throughout analysis of the results.)

"You will see that a sample will either be more sweet (acid) or less sweet (acid) or the same as the one before it. Would you taste the first two and say how the second compares with the first. Now would you taste the third and say how it compares with the second" (etc.).

When the control subjects were being used they alternated with the experimental subjects.

RESULTS

The mean and standard deviations of the relative intensity ratings for each comparison on each experimental run are set out in Table 1. It will be noticed that the mean values of all comparisons, including those associated with a change in the component not being judged, $A_{a.b.}$, $A_{b.a.}$, $S_{c.d.}$, $S_{d.c.}$, are near to zero, suggesting that neither concordant nor contrasting responses were occurring. This interpretation makes the assumption that mean ratings are an adequate measure of the situation, an assumption that has been made in previous studies. However, examination of the standard deviations of the relative-intensity comparisons reveals that they are greater for those comparisons involving a change in the component not being judged than for those comparisons in which the total mixture actually remained unchanged. The application of a test of homoscedasticity (Bartlett, 1934) reveals that the results of all judgments are heteroscedastic ($p<.02$), but when the two groups of comparisons are considered separately they are both homoscedastic. In other words the distributions of the relative intensity ratings of pairs of identical stimuli, regardless of which component is being compared, are similar whereas the distributions of the relative intensity ratings of the constant component in those instances where the other component varied, regardless of which it was or in which direction it moved, are also similar to each other but significantly different from the former distributions.

Table 2 shows the frequencies of the ratings for the two types of comparison. Comparisons of identical stimulus mixtures (Table 2-A) produce unimodal distributions with the erratic exception of judgment $S_{d.d.}$ On the other hand, comparisons in which the component not being rated was changed (Table 2-B) resulted in bimodal distributions. If either contrasting or concordant responding was occurring alone, then these latter distribu-

Table 2. Pooled frequencies of ratings, (2nd stimulus compared with 1st tasted within a comparison), over similar stimulus comparisons from experimental runs.

A. Comparisons of identical stimulus mixtures, based on 1st and 2nd comparisons.

Rating scale value	Judgment elicited			
	$A_{a.a}$	$A_{b.b}$	$S_{c.c}$	$S_{a.a}$
+3	3	1	4	1
+2	16	11	9	11
+1	12	10	7	6
0	15	17	17	11
−1	3	6	6	5
−2	6	6	6	14
−3	1	5	7	8
Σ	56	56	56	56
mean	0.63	0.04	−0.04	−0.46
s.d.	1.44	1.57	1.75	1.79

B. Comparisons of stimulus mixtures differing in one component only, based on 3rd and 4th comparisons where appropriate.

Rating scale value	Judgment elicited			
	$A_{a.b}$	$A_{b.a}$	$S_{c.d}$	$S_{d.c}$
+3	11	11	6	8
+2	5	12	4	8
+1	4	0	7	0
0	1	0	4	2
−1	2	2	2	3
−2	7	5	10	8
−3	12	12	9	13
Σ	42	42	42	42
mean	−0.12	0.21	−0.38	−0.43
s.d.	2.49	2.56	2.15	2.43

tions would also be unimodal with the mode situated towards one or other extreme. In fact both effects have occurred. The population of subjects is not responding in a homogeneous manner and it is for this reason that the variances of the two groups are so different.

The distributions of ratings made by the control group are shown in Table 3. The results for comparisons of identical stimulus mixtures are homoscedastic and so are those for comparisons of the component that varied, but all the results for the control group when considered together are heteroscedastic. In this group, unlike the experimental subjects, there is more agreement between subjects when they are making comparisons of the component that is in fact varying than when comparing identical stimulus mixtures. These results indicate that the changes in concentration of both stimulus components are being adequately detected by the subjects in spite of the presence of the other component and in spite of any residual masking from the previously tasted stimuli in the series.

It might be argued that the distributions in Table 2-B are due to some kind of guessing strategy on the part of the subjects, that is, subjects can detect some kind of difference when the component other than the one they are comparing is changed but are not sure as to what it is and consequently allocate their responses randomly (Cheatham 1952). Inspection of Table 4 reveals that subjects are being more consistent from one trial to the next than would be expected if they were producing contrasting or concordant responses by chance. The indeterminate subjects are those who made the same response to no stimulus change as they made to a real change in one of the components, and consequently cannot be considered as exhibiting either type of behavior. If the indeterminate responses are equally allocated to the four other cells the value

Table 3. Pooled frequencies of ratings, (2nd stimulus compared with 1st tasted within a comparison), over similar stimulus comparisons from control runs.

A. Comparisons of identical stimulus mixtures, based on 1st and 2nd comparisons.

Rating scale value	Judgment elicited			
	$S_{a.a}$	$S_{b.b}$	$A_{c.c}$	$A_{d.d}$
+3	1	1	0	2
+2	3	4	2	1
+1	1	0	0	5
0	7	5	6	2
−1	2	1	3	3
−2	1	3	4	2
−3	1	2	1	1
Σ	16	16	16	16
mean	0.19	−0.13	−0.63	0.19
s.d.	1.51	1.93	1.36	1.71

B. Comparisons of stimulus mixtures differing in one component only, based on 3rd and 4th comparisons where appropriate.

Rating scale value	Judgment elicited			
	$S_{a.b}$	$S_{b.a}$	$A_{c.d}$	$A_{d.c}$
+3	0	10	0	4
+2	0	2	0	6
+1	1	0	1	1
0	0	0	1	0
−1	0	0	1	0
−2	2	0	3	1
−3	9	0	6	0
Σ	12	12	12	12
mean	−2.50	+2.83	−2.00	+1.92
s.d.	1.12	0.41	1.29	1.31

Table 4. Frequency table showing the relation between the types of responses made by subjects on the first and the second trial runs.

First trial	Second trial: Concordant	Contrasting	Indeterminate	Σ
Concordant	19	3	1	23
Contrasting	5	17	1	23
Indeterminate	4	1	5	10
Σ	28	21	7	56

of the phi-coefficient is 0.5, which is significant beyond 1% level.

The actual amount of the perceived changes in intensity cannot be measured in absolute terms, because the amount is relative and affected by previously encountered changes in the series of mixtures tasted.

The series of five stimuli gives four comparative ratings between stimuli, and hence three intervals between ratings. Changes in ratings over these three intervals, irrespective of their direction, reflect changes in the perceived differences between stimuli. Taking runs *E*1, *E*2, *E*5, and *E*6 as one group, *t*-tests between the three intervals show differences significant beyond the 5% level in the mean moduli of changes in ratings between the second and third intervals, but not between the first and second, although the second interval shows a greater shift than the first, probably from the negative recency effect (Jarvik, 1951). This is consistent with expectations, for the first three comparisons are between identical pairs of stimuli. For the runs *E*3, *E*4, *E*7, and *E*8 (runs in which intensity reversals occurred) differences in mean moduli of shifts between all three intervals are significant beyond the 1% level by *t*-test. This means that a contrast effect is occurring over the last comparative rating; subjects who detect a change—in whatever direction—between the third and fourth stimulus detect a much bigger opposite change between the fourth and fifth, although the actual change is equal and opposite to the one preceding. This behavior is consistent with the A.L. theory, but only if the actual direction of the changes for half the subjects (the concordant subjects) is ignored. The perceived magnitude of the shifts in sweetness due to acid changes or acidity due to sucrose changes is clearly influenced by immediately preceding taste experience, for the previous stimuli serve as subjective reference points.

DISCUSSION

The results show that both concordant and contrasting responses can occur as types of response behavior, so either theory is excluded as an adequate general description of responses over the near-threshold range. The effects of changes in one component of a sucrose-citric acid mixture on changes in the perceived intensity of sensations associated with the other constant component are as great, when expressed on a rating scale, as the perceived actual changes associated with the variable component itself (compare Tables 2-B and 3-B). On the basis of our results, at least one sort of serial comparative judgment can be elicited in which acid can make sucrose more or less sweet, and sucrose make citric acid more or less sharp: the two sorts of change appear to be associated with two separate groups of tasters, so that it is misleading to treat all tasters as equivalent, as previous workers have done. The evidence does not tell us what the two groups of tasters are; in similar studies in sensory modalities other than taste, comparable divisions of subjects have been made on personality variables (Eysenck, 1942) and on strategies that a subject might adopt in ambiguous situations (Vanderplas and Blake, 1949; Broadbent, 1958).

If the results of Kamen *et al.* held in our experiment we would expect to get contrasting responses when sucrose concentration was increased, but concordant responses when acid is increased. If Pangborn's (1960) results held, we would expect to get contrasting responses throughout. Since previous studies use analyses based simply on mean responses to stimuli, we cannot disentangle all the factors that could account for differences between their studies and our own, but we question the generality of their findings and the validity of their conclusions over the range of concentrations used in our experiment precisely because they have neglected variables that are known to affect the perception of complex stimuli or stimuli encountered in series (George, 1917; Jarvik, 1951; Estes, 1954; Lawrence and Laberge, 1956).

It may be argued that we have not been entirely fair to the A.L. theory, since Engel and Parducci (1961) have revised it and put it into a different and more complex form to cover the case of a variable stimulus judged against a variable background.

This is an extension of the A.L. theory in that one component is identified as "figure" and the other as "background." This third theory might be reconciled with, but only with, the contrasting responses, for if the subject picks on the variable component as his background, the constant component should shift in contrasting fashion, whereas if he has picked on the constant component as background then prediction is indeterminate.

CONCLUSIONS

Current psychological theories can be employed to predict the occurrence of either concordant or contrasting responses, but the fact that we have found both indicates that the situation is more complex than can be accounted for by either theory taken on its own. The conflicting results between previous studies and our own can be the result of inadequate analysis of results or differences between the tasters in their previous experience of similar stimuli, either on trial sessions, or as reference stimuli, or on early experimental tests as compared with later ones.

We conclude that, in the near-threshold range of stimulus intensities, perceptual processes are as important as the stimulus identities or intensities themselves in determining what subjects will say they can taste in a mixture. In order to specify the interaction effects of taste mixture components we must therefore hold constant, or separate out in analysis, the various sources of bias such as time-errors or the subjects' selective expectations about what stimulus mixtures are to be encountered (Gregson, 1961). Also, if possible, we should screen the subjects to determine whether they have a predilection to respond in some habitually erroneous fashion when complex judgments are evoked.

The food technologist needs information on the perception of taste mixtures as a rational basis for product formulation and development. Such information should indicate what generality can be claimed for it: if potential tasters perceive small changes in different ways because they do not constitute a homogeneous group of tasters, then product changes of the perceived magnitudes involved in our experiment cannot be expected to lead to consistent changes in acceptability.

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