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INTERACTION OF SUCROSE AND CALCIUM CYCLAMATE ON PERCEIVED INTENSITY OF SWEETNESS[a,b]

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If we mix various proportions of 5 and 10% sucrose solutions, we will find that the perceived intensity of sweetness of the mixtures will lie between the perceived intensities of the original solutions. Specifically, the subjective intensities of the mixtures should be approximately geometrically proportional to the relative amounts of each of the original solutions that comprise the mixture. In this case, the effects of mixing the solutions are said to be additive.

Consider next the case where, instead of two sucrose solutions, we have one sucrose solution and one of another type of sweetening agent, calcium cyclamate. Are the effects of mixing two different sweetening agents also additive? Will the sweetness of the mixture be proportional to the amounts of each pure solution in the mixture, or will the sweetness be greater or less than of either pure solution alone?

The purpose of this study was to determine the effects of mixing, in different proportions, various concentrations of two chemically distinct sweeteners upon the perceived intensity of sweetness.

EXPERIMENTAL

Subjects. The subjects (*Ss*) were 16 employees of this Institute, most of whom had participated in previous sweetness studies *(2)*. Those who had no prior experience were selected from candidates who demonstrated ability in discriminating among different sucrose concentrations.

Method. The method used was that of single stimulus with a nine-interval rating scale of intensity. Alternate intervals were anchored with the following descriptions of intensity: *None, slight, moderate, strong,* and *extreme.* The intervals were assigned successive integers from 1 *(none)* to 9 *(extreme)* and the ratings then treated quantitatively.

Concentrations of sucrose and cyclamate. The sucrose used to prepare the solutions was an analytical reagent at least 99.991% pure. The calcium cyclamate was Du Pont *Cylan.* Charcoal-filtered distilled water was used as the solvent.

Estimates of the concentrations of sucrose and cyclamate required to give mean intensity ratings of 2, 4, 6 and 8, were available from both published *(2)* and unpublished[c] data of Schutz and Pilgrim. For sucrose, these concentrations were 2.31%, 5.79%, 14.63%, and 37.07%, respectively. For cyclamate the corresponding concentrations were: .067%, .166%, .465%, and 1.540%. Note that the concentrations are approximately logarithmically spaced within each set.

Solutions. At each level, two solutions of mixtures of sucrose and cyclamate were

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[c] Personal communication.

prepared, as well as solutions of sucrose and cyclamate alone. The first mixture consisted of two-thirds of the sucrose solution and one-third of the cyclamate. In the second mixture, the proportions were reversed. For example, at Level I (estimated intensity rating of 2), there were 4 solutions: (a) 2.31% sucrose; (b) 1.54% sucrose plus .022% cyclamate; (c) .77% sucrose plus .045% cyclamate; (d) .067% cyclamate. Thus, mixture (b) consisted of two-thirds (a) and one-third (d); and mixture (c) consisted of one-third (a) and two-thirds (d).

The solutions for the other 3 levels were similarly prepared. Table 1 presents the concentrations, by level, of the solutions containing only sucrose, only cyclamate, and the mixtures.

TABLE 1

Concentrations of pure solutions of sucrose and calcium cyclamate and of Their Mixtures

Level	Estimated subjective intensity of sweetness	Sweetener is: (a) All sucrose		(b) ⅔ Sucrose; ⅓ Cyclamate		(c) ⅓ Sucrose; ⅔ Cyclamate		(d) All cyclamate	
		Su.	Cy.	Su.	Cy.	Su.	Cy.	Su.	Cy.
I	2	2.31% [1]	0%	1.54% [1]	.022%	.77%	.045%	0%	.067%
II	4	5.79%	0%	3.86%	.055%	1.93% [1]	.111%	0% [1]	.166%
III	6	14.63% [1]	0%	9.75% [1]	.155%	4.88%	.310%	0%	.465%
IV	8	37.07%	0%	24.71%	.510%	12.36% [1]	1.030%	0% [1]	1.540%

[1] Denotes solutions and mixtures presented to *S*s on days 1 and 3. Other solutions and mixtures were presented on days 2 and 4.

Procedure. The 16 solutions (4 solutions at each of 4 levels) were divided into 2 groups of eight. On testing days 1 and 3, the 8 solutions indicated by a footnote symbol in Table 1 were presented to the *S*s; on testing days 2 and 4, the other 8 solutions were evaluated. Order of presentation of the samples was balanced. All 4 testing days were spaced approximately 2 weeks apart. Fresh solutions were prepared for each test day.

*S*s sat in a semi-enclosed testing booth. Six ml. samples in coded one-ounce glasses were presented one at a time through a turntable in a wall separating the booth from the serving area. After rating each sample, *S* rinsed his mouth *ad libitum* with charcoal-filtered distilled water. The time between the rating of one solution and the presentation of the next was 45 seconds.

RESULTS

The mean intensity ratings for each solution over two sessions are presented in Table 2. It was estimated that the successively increasing concentrations of the sucrose solutions alone and of the cyclamate solutions alone would yield intensity ratings of 2 (Level I), 4 (Level II), 6 (Level III), and 8 (Level IV). The estimates were somewhat more accurate for the sucrose solutions than those for the cyclamate. For both types of sweeteners the set of stimulus concentrations is considered adequate to test for additivity of mixtures over a wide range of subjective intensities.

If the intensities of the mixtures possess the property of additivity, then their ratings should lie between those of the pure cyclamate and the pure sucrose solutions. Inspection

TABLE 2

Mean intensity ratings for each solution and mixture

Level	Sweetener is: (a) All sucrose	(b) ⅔ Sucrose; ⅓ Cyclamate	(c) ⅓ Sucrose; ⅔ Cyclamate	(d) All cyclamate
I	2.25	2.41	2.06	2.06
II	3.75	4.22	3.91	3.62
III	6.03	6.59	6.59	5.44
IV	7.69	7.81	7.66	7.72

of Table 2 suggests that at the lowest and highest stimulus concentrations (Levels I and IV), the intensity of the mixtures are not markedly different from the intensities of the pure solutions. For the intermediate levels, however, the intensities of the mixtures are always higher than those of the pure solutions.

An analysis of variance was performed to test whether the apparent departures from additivity, particularly at the second and third levels, are significant. The breakdown of the sources of variation and the results of the analysis are shown in Table 3. The ratings of the two mixtures at each intermediate level are significantly greater than the ratings of the pure sucrose and cyclamate solutions. This effect is not evident for either the highest or lowest levels.

The significance of "L_1" and "L_2" in Table 3 merely means that the intensity of sweetness increases as "linear" and "cubic" functions of stimulus concentrations. "Linear" and "cubic" are in quotation marks because the sums of squares for "L_1" reflects some cubic as well as linear components. Similarly, the sum of squares for "L_2" reflects both

TABLE 3

Analysis of variance of sweetness ratings

Source of variation	df	Mean square	Level of significance
T_1 (within Level I)	1	2.26	
T_1 (within Level II)	1	1.53	
T_1 (within Level III)	1	2.82	
T_1 (within Level IV)	1	.12	
T_2 (within Level I)	1	.20	
T_2 (within Level II)	1	4.50	.05
T_2 (within Level III)	1	23.63	.001
T_2 (within Level IV)	1	.03	
$T_1 T_2$ (within Level I)	1	.20	
$T_1 T_2$ (within Level II)	1	.28	
$T_1 T_2$ (within Level III)	1	2.82	
$T_1 T_2$ (within Level IV)	1	.28	
T_1 (within Level I) — S_2	1	.63	
T_1 (within Level II) — S_2	1	1.53	
T_1 (within Level III) — S_2	1	.07	
T_1 (within Level IV) — S_2	1	.03	
T_2 (within Level I) — S_2	1	1.32	
T_2 (within Level II) — S_2	1	2.00	
T_2 (within Level III) — S_2	1	.95	
T_2 (within Level IV) — S_2	1	2.00	
$T_1 T_2$ (within Level I) — S_2	1	1.32	
$T_1 T_2$ (within Level II) — S_2	1	2.53	
$T_1 T_2$ (within Level III) — S_2	1	.01	
$T_1 T_2$ (within Level IV) — S_2	1	3.12	
L_1	1	1953.12	.001
L_2	1	334.76	.001
$L_1 L_2$	1	.50	
S_2	1	6.57	.05
$L_1 S_2$	1	6.12	.05
$L_2 S_2$	1	.63	
$L_1 L_2 S_2$	1	.28	
Judge (within day)	60	6.97	.05
Judge-treatment interaction: within day (Error)	420	1.33	
Total	511		

Note: Symbols refer to comparisons of mean ratings: (See Table 1 or 2)
T_1 — Sweeteners (a) and (b) *vs.* (c) and (d)
T_2 — Sweetners (a) and (d) *vs.* (b) and (c)
T_1T_2 — Sweeteners (a) and (c) *vs.* (b) and (d)
L_1 — Levels I and II *vs.* III and IV (Linear component)
L_2 — Levels I and III *vs.* II and IV (Cubic component)
L_1L_2 — Levels I and IV *vs.* II and III (Quadratic component)
S_2 — Days 1 and 2 *vs.* 3 and 4

linear and cubic components. To determine the significance of the entirely linear and entirely cubic mathematical relationships, we used orthogonal polynomials as described by Fisher and Yates *(2)*. The sums of squares for the linear component increased to 2276.33 and the sums of squares for the cubic component decreased to 11.56. We may conclude that the ratings and logarithms of the stimulus concentrations are linearly related, and that the cubic component is not too important though still statistically significant at the .01 level.

The significance of "S_2" indicates that the ratings of intensity were higher on days 3 and 4 than on days 1 and 2. The interaction between replication and the linear component of stimulus concentration (L_1S_2) is also statistically reliable. It is possible that during the first 2 days *S*s were reluctant to endorse the 8th and 9th categories because, had even stronger concentrations been later presented, they would have no "room" for expressing their more intense sensations. However, once having learned the range of concentrations during the first 2 days, they would be less hesitant to use the extreme categories during the second 2 days. This explanation has no special relevance to the main conclusions of the experiment.

DISCUSSION

A practical implication of the results is that if these two sweetening agents are both used in a product, the sweetness will probably be greater than would be expected on the basis of simple additivity. Whether the same conclusion would hold when pairs (or triplets) of other sweeteners are employed is to be determined in future investigations.

At least two alternative explanations might account for this fact of non-additivity in the middle range of concentrations. The first is that the sweet receptors may be differentially sensitive to the sucrose and cyclamate molecules. If they are, then a mixture of the two sweeteners would be expected to stimulate a greater number of receptors, and consequently, to bring about a greater perceived intensity.

The alternative explanation assumes that the presence of bitter reduces the perceived intensity of sweet. Several *S*s and the experimenter himself observed that many of the solutions which contained cyclamate were somewhat bitter. If these observations are valid, then the mixtures of sucrose and cyclamate could be expected to taste sweeter than the pure solutions because the bitter component of the cyclamate is diluted in the mixture and hence suppresses the sweet taste to a lesser degree. A further extension of this reasoning is: If two sweetening agents have no bitter component, then the effects of mixing them are more likely to be additive than if either or both are somewhat bitter. The implications of this explanation can be subjected to experimental test.

SUMMARY

Pure solutions of two sweetening agents, calcium cyclamate and sucrose, and mixtures of these solutions were rated by judges for intensity of sweetness. At the highest and lowest solution concentrations, the perceived intensities of the mixtures did not depart markedly from the perceived intensities of the average of the pure solutions comprising the mixtures. At moderate solution concentrations, however, the perceived intensities of the mixtures were significantly higher than the intensities of the pure solutions. The practical and experimental implications of this finding were discussed.

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