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Interactions in caffeine—sucrose and coffee—sucrose mixtures: evidence of taste and flavor suppression

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Abstract

Taste-taste and flavor-taste interactions (suppression) in caffeine-sucrose and coffee-sucrose mixtures were determined. Similar interactions for both types of mixtures showed an extended hypoadditivity effect for overall taste or flavor intensity (percentage of suppression about 30-40%). Furthermore, mutual suppression among the components has been determined. Firstly, the physical intensity of the suppressive component controls the amount of suppression of the other component. Thus, the suppression of bitterness and coffee flavor qualities increase when sucrose levels increase, and similarly, the suppression of sweetness increases when caffeine or coffee levels rise. Secondly, the magnitude of suppression depends upon the quality of the suppressive component. Comparisons of the reciprocal actions were made at similar subjective intensities of the mixture's constituents in isolation. The results showed that, at similar perceived intensities, caffeine bitterness or coffee flavor were suppressed by sucrose but sweetness was not affected by caffeine or coffee.

Introduction

Interactions among components are common in both taste and olfactory mixtures and therefore must be considered in studies of chemical mixtures, especially food stimuli.

Part of the research effort in this subject has focused on mixtures of stimuli within one sensory modality like taste (Bartoshuk, 1975; Lawless, 1979; Curtis et al., 1984; Kroeze and Bartoshuk, 1985; Frank and Archambo, 1986) or smell (Cain, 1975; Laing and Willcox, 1983; Laing, 1987). Another approach explores the oral perception of mixtures of stimuli across different modalities. Psychophysical studies include taste-viscosity (Christensen, 1980a, b; Izutsu et al., 1981), taste-odor (García-Medina, 1981; Hornung and Enns, 1984, 1986), taste-temperature (Bartoshuk et al., 1982; Calviño, 1986; Frankmann and Green, 1987) and taste-pungency (Lawless and Stevens, 1984; Cometto-Muñiz et al., 1987; Cowart, 1987) mixtures. These binary mixtures resemble natural chemical stimuli, including food stimuli where odor, taste, viscous and pungent qualities at a given temperature simultaneously stimulate the receptor systems.

Mixture interactions described as enhancement or suppression indicate that the mixtures of chemicals are often perceived differently from the sum of their components. Departures from expected additivity of the responses to mixtures were shown by psychophysical (Lawless, 1979; Gillan, 1982, 1983) and neurophysiological (Hyman and Frank, 1980a, b; Boudreau et al., 1981) studies. This evidence strongly suggests that mixture interactions usually take the form of mixture suppression. Furthermore, a weakening of the intensity of one or both components in a binary mixture has been reported (Bartoshuk, 1975, 1979; Kroeze, 1978, 1979; Frank and Archambo, 1986).

Although taste suppression describes quite well the interaction of a given pair of tastants, it is still far from fulfilling the wish to characterize the subjective behavior of a mixture where the flavor of a substance is added to taste. Therefore, one interesting way to explore this subject is to study what happens when two taste qualities such as sweetness (sucrose) and bitterness (caffeine) interact and then compare these results with those obtained from a mixture wherein one component also has flavor, i.e., coffee and sugar.

We analyzed in the first experiment the mutual interactions between caffeine and sucrose in a mixture with respect to their individual qualities as well as to their total taste intensity (TTI). In a second experiment the subjects estimated the individual flavor and taste intensities for different mixtures of coffee-sugar as well as the emerging total flavor intensity (TFI) of these mixtures. Thus, the aim of this paper is to answer several questions. Does each compound interact with other? Does the interaction affect distinctly both compounds? What degree of taste or flavor suppression occurs in each mixture?

Materials and methods

Experiment 1

Subjects. Fourteen subjects, seven males (average age: 21.3 ± 1.7 years) and seven females (average age: 20.7 ± 3.8 years) participated. All were undergraduate students and had previous experience in psychophysical taste experiments.

Stimuli. Four concentrations of caffeine (C): 6, 13, 26 and 52 mM, three of sucrose (S): 146, 292 and 585 mM and their twelve possible binary mixtures (C-S) served as stimuli. Chemicals used were reagent grade or equivalent and were dissolved in distilled water.

The range of intensities of both compounds was approximately the same, and the lowest unmixed concentrations were chosen sufficiently above threshold so that all subjects could taste the sweetness of 146 mM sucrose and the bitterness of 6 mM caffeine.

Procedure. The subjects made intensity judgments of the above mentioned stimuli and this task was replicated in two separate sessions. All stimuli were presented once per session in a random order and subjects were required to sip and spit the entire stimulus volume (4.0 ml). Between samples, a rinse with distilled water at 25°C was made. The temperature of the stimuli was kept at 37°C (± 2°C). Stimulus duration was 3 s, and inter-stimulus intervals ranged from 30 to 90 s depending on the subject.

To make their judgements, subjects employed a modification of the method of magnitude matching (Stevens and Marks, 1980). By means of this procedure the subjects were instructed to make numerical estimations of the perceived taste intensity, using the first stimulus (6 mM caffeine) as the standard for comparison. When mixtures were evaluated the subjects gave a number for total taste intensity and then broke down that number into sweetness and bitterness. Subjects were instructed to make numerical judgements of all three sensations on the same scale.

Data analysis. Data were summarized in terms of the geometric mean of each subject's average response for each stimulus.

Some subjects gave estimates of zero when they evaluated the contribution of sweetness and bitterness to the overall taste intensity. To obtain geometric means across subjects, zero values for each subject were replaced by a value one logarithmic unit below the lowest estimation given by that participant (Enns et al., 1979).

Subjects were free to choose their own modulus. To eliminate the scatter due to differences in modulus across subjects their judgments were averaged and normalized as described in the literature (Lane et al., 1961; Cain and Moskowitz, 1974).

The percentages of suppression (or enhancement) for each type of response—sweetness (Sw), bitterness (Bi) and total taste intensity (TTI)—were calculated. Suppression scores per subject were obtained by calculating the difference between the geometric mean of the unmixed or pure components (p) and the geometric mean of the corresponding estimates of the mixtures (m). These differences were then expressed as a percentage of the corresponding quality estimates of the unmixed components, resulting in the following suppression scores:

$$\frac{Sw_p - Sw_m}{Sw_p} \times 100 \qquad \frac{Bi_p - Bi_m}{Bi_p} \times 100 \qquad \frac{TTI_p - TTI_m}{TTI_p} \times 100$$

Experiment 2

Subjects. Fourteen undergraduate students, (seven males and seven females participated, but one female stopped half-way through the experiment. Males (average age: 21.3 ±1. 7 years) and females (average age: 21.1 ± 2.0 years) had experience in sensory evaluation of taste and flavor stimuli. There were 10 participants (seven males and three females) common to both experiments.

Stimuli. Four coffee solutions (Co): 10, 20, 40 and 100% v/v, three sucrose concentrations (S): 88, 175 and 351 mM and their twelve possible binary mixtures (Co-S) served as stimuli.

The 100% v/v coffee solution was prepared as stated previously (García-Medina, 1981). Roasted beans of coffee were ground and mixed with distilled water in 1:10 w/v ratio. To prepare coffee-sugar mixtures, coffee dilutions were added to three different amounts of sugar (3, 6 or 12 g) to complete 100 ml of solution. In order to assess the uniformity of the solutions from session to session, measurement of the solid content was performed in triplicate. In every session, 5 ml of each coffee solution were placed in a precipitation glass in a stove at or near 100°C and left to dry for 6 h. The average results from the weakest to the strongest solution were: 0.01 g ± 1.26×10^{-4} g (10% v/v); 0.02 g ± 3.28×10^{-4} g (20% v/v); 0.04 g ± 1.5×10^{-3} g (40% v/v) and 0.10 g ± 2.89×10^{-3} g (100% v/v).

Procedure. Stimuli were evaluated as in taste-taste mixtures. Before starting the experiment and between stimuli, subjects rinsed their mouths, first with tap water at 25°C and then with tap water at 50°C. Furthermore, stimuli were evaluated by means of the same psychophysical method as in Experiment 1. In two separate sessions, subjects made replicate estimations of each sample against the same standard, the flavor of a 20% v/v coffee solution without sugar.

Data analysis. Geometric means of judgements and percentages of suppression were calculated in the same way as those in Experiment 1.

Results

Experiment 1

Bitterness perception. Figure 1 shows the growth of bitterness of the twelve bitter-sweet mixtures as well as the four pure bitter stimuli. As expected the contribution of sucrose to bitter suppression was more evident at low concentrations of caffeine (6 and 13 mM) than at high concentrations (26 or 52 mM). To confirm this interactive pattern, the logarithms of the normalized judgements of bitterness were analyzed with a repeated measures analysis of variance (O'Mahony, 1986). Main effects for caffeine ($F_{(3,39)}$ = 60.1; P<<0.001), sucrose ($F_{(3,39)}$ = 39.1; P<<0.001) and the interaction between caffeine and sucrose ($F_{(9,117)}$ = 4.9; P<0.001) were highly significant.

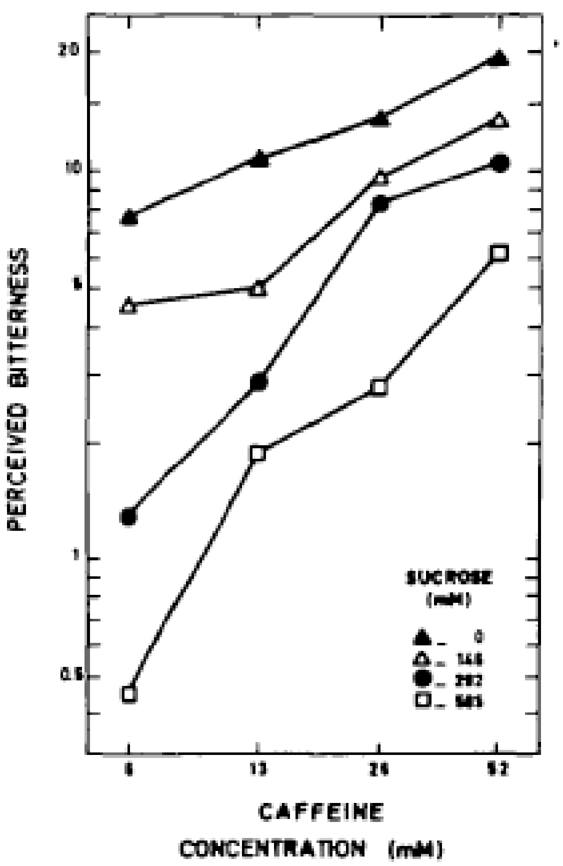


Figure 1. Bitterness of caffeine-sucrose mixtures as a function of caffeine concentration. Bitterness of caffeine without sucrose is also shown.

In addition to the ANOVA test, Dunnett tests for post-hoc comparisons (O'Mahony, 1986) were performed to compare the bitter intensity of caffeine alone with the bitterness of caffeine-sucrose mixtures. The comparisons showed that 292 and 585 mM sucrose produce a significant reduction in the perceived bitterness. Thus, bitter intensities of the mixtures, which contained 292 or 585 mM sucrose, showed an increase in relative steepness of the slope (Figure 1), which is comparatively flat in the unmixed state. The exponents and the standard deviations of the bitter functions varied from 0.43 ± 0.30 for caffeine alone to 0.54 ± 0.30, 1.04 ± 0.67 and 1.18 ± 0.66 for caffeine plus 146, 292 and 585 mM sucrose respectively.

Furthermore, to explore the difference in the magnitude of bitter perception of caffeine with and without sucrose, the percentages of bitter suppression across the mixtures were calculated. Table I provides the values for bitter suppression as well as the significant differences between the mixed and unmixed condition.

Table I. Percentages of suppression (%) for bitterness (Bi), sweetness (Sw) and total taste intensity (TTI)

C−S (mM−mM)	Bi (%)	Sw (%)	TTI (%)
6−146	(3) −	(3) 45.7**	(2) 29.8**
6−292	(1) 65.9**	(5) −	32.2**
6−585	91.8**	(10) −	(1) 27.4**
13−146	(1) 46.5**	(3) 30.3*	37.0**
13−292	67.0**	(5) −	(1) 41.9**
13−585	(2) 64.3**	(3) −	36.3**
26−146	(4) −	60.2**	(1) 34.4**
26−292	(2) 33.3*	53.2**	42.0**
26−585	71.7**	(2) −	48.0**
52−146	(3) −	81.5**	(1) 39.1**
52−292	(1) 42.3*	67.1**	50.2**
52−585	(1) 54.8**	42.1*	48.0**

Percentages of suppression significant at P<0.05 (*) or P<0.01(**).
Numbers in parenthesis indicate the subjects who showed enhancement or simple additivity behavior.
Percentages of suppression were not calculated when there were no significant differences in the perceived intensity between the mixed and unmixed condition.

Although the overall effect is masking or suppression of bitterness, about 10% of the judgments showed enhancement or simple additivity behavior (see numbers in parenthesis in Table I). Notice that the mixtures with non-significant bitter suppression are related to a greater frequency of non-suppressive judgments.

Sweetness perception. Sensory responses for sucrose alone and for caffeine-sucrose mixtures were plotted against concentration of sucrose in Figure 2.

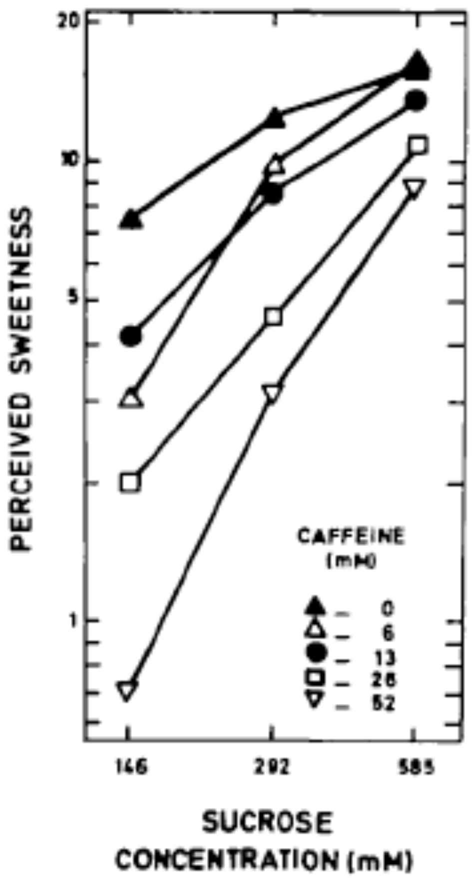
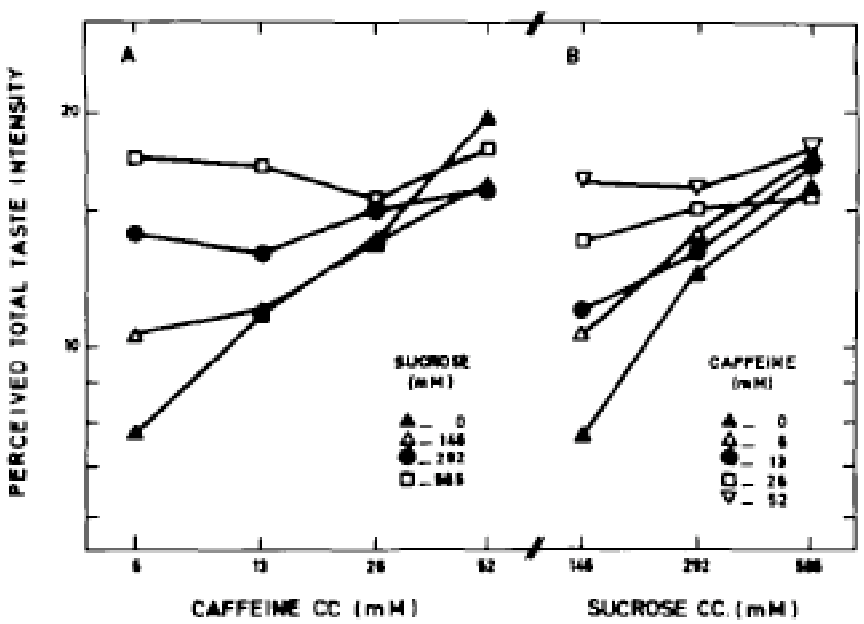


Figure 2. Sweetness of caffeine-sucrose mixtures as a function of sucrose concentration. Sweetness of sucrose without caffeine is also shown.

Sweetness intensity was reduced when caffeine is present, with this suppressive action being greater at the lower sucrose levels. The reduction of sweetness was confirmed with a repeated measures ANOVA performed over the normalized judgments of sweetness log transformed). Significant main effects were found for sucrose ($F_{(2,26)}$ = 23.1; P<<0.001) and caffeine concentration ($F_{(4,52)}$ = 10.3; P<<0.001), as well as a significant sucrose by caffeine interaction ($F_{(8,104)}$ = 38.4; P<<0.001). This interactive effect is reflected in the slopes of the sweetness functions which show a continuous tendency to steepen with increasing caffeine. In the presence of 0, 6, 13, 26 and 52 mM caffeine the sweetness slopes and their standard deviations are, respectively, 0.54 ± 0.32, 1.20 ± 0.49, 0.85 ± 0.57, 1.24 ± 0.78 and 1.81 ± 0.81.

Subsequent multiple comparisons between the perceived sweetness of samples with and without caffeine were performed by Dunnett tests. The degree of mixture suppression observed in the 12 mixtures varied widely, from no significant reduction to an 81.5% reduction in the sweetness response. The failure to observe mixture suppression was due to several judgments of enhancement or additivity (about 20% of the judgments). Thus, numbers in parenthesis in the sweetness column of Table I showed that a great frequency of non-suppressive judgements is associated with a non-significant reduction of sweetness.

Total taste intensity. Total taste intensity (TTI) of bitter-sweet mixtures is depicted as a function of bitter and sweet components in Figure 3 (pictures A and B). Figure 3A shows the relationship between the total perceived taste intensity and the caffeine concentration. Here, the estimations of the bitter component alone at higher concentrations tend to be equal or higher than the ratings of TTI. To confirm this interactive pattern the TTI judgments (log transformed) of caffeine-sucrose and unmixed caffeine solutions were analyzed by a repeated measures ANOVA. Both caffeine ($F_{(3,39)} = 7.8$; $P<<0.001$) and sucrose concentration ($F_{(3,39)} = 19.1$; $P<<0.001$) produced significant main effects, and the caffeine by sucrose interaction was also significant ($F_{(9,117)} = 9.8$; $P<<0.001$).



<u>Figure 3</u>. <u>A</u>. Total perceived intensity of caffeine-sucrose mixtures as a function of caffeine concentration. <u>B</u>. Same data as in A, depicted as a function of sucrose concentration. In both cases filled triangles represent bitterness of pure caffeine, or sweetness of pure sucrose solutions.

TTI exhibited a quite similar pattern when data were plotted against concentration of sucrose (Figure 3B). While caffeine mixed with the lower concentration of sucrose increases the overall taste intensity, caffeine added to high concentrations of sucrose eliminates the differences between intensities of mixture solutions and the unmixed sucrose stimuli. The TTI judgments (log transformed) of caffeine-sucrose and unmixed sucrose solutions were analyzed by a repeated measures ANOVA and the results indicate that both sucrose ($F_{(2,26)} = 7.7$; $P<<0.001$) and caffeine concentration ($F_{(4,52)} = 6.0$; $P<<0.001$) produced significant main effects, and the sucrose by caffeine interaction was also significant ($F_{(8,104)} = 15.8$; $P<<0.001$).

In addition to the ANOVA tests, Dunnett tests for post-hoc comparisons were performed to compare the taste intensity of the unmixed components with the total intensity of the caffeine-sucrose mixtures. The results confirmed the subadditivity, i.e., the total mixture intensity is always less than the sum of the unmixed components.

The same kind of information, but performed on percentages of total taste suppression, provided another measure of taste interactions. Analyzing suppression values, a similar pattern was evident for all mixtures (Table I). Thus, the average suppression value for TTI increases slightly with caffeine concentration (6 mM = 30%, 13 mM = 38%, 26 mM = 42% and 52 mM = 46%) and sucrose concentration (146 mM = 35%, 292 mM = 41% and 585 mM = 40%).

Experiment 2

Coffee flavor perception. Figure 4 shows the perception of coffee flavor for the twelve coffee-sugar mixtures and the four unmixed coffee dilutions. The magnitude of coffee flavor is reduced when sugar is present. This effect was tested by examining the coffee flavor data (logarithms of the normalized judgments) with a repeated measures ANOVA. The main effects for coffee ($F_{(3,39)}$ = 27.5; $P<<0.001$) and sucrose ($F_{(3,39)}$ = 96.3; $P<<0.001$) were highly significant, and the coffee by sucrose interaction was also significant ($F_{(9,117)}$ = 2.1; $P<0.05$). This effect causes the slope of the flavor functions to steepen and rise (Figure 4). Thus, the exponents of the power functions and their standard deviations varied from 0.47 ± 0.2 for coffee alone to 0.64 ± 0.23, 0.73 ± 0.29 and 0.65 ± 0.32 for coffee plus 88, 175 and 351 mM sucrose respectively.

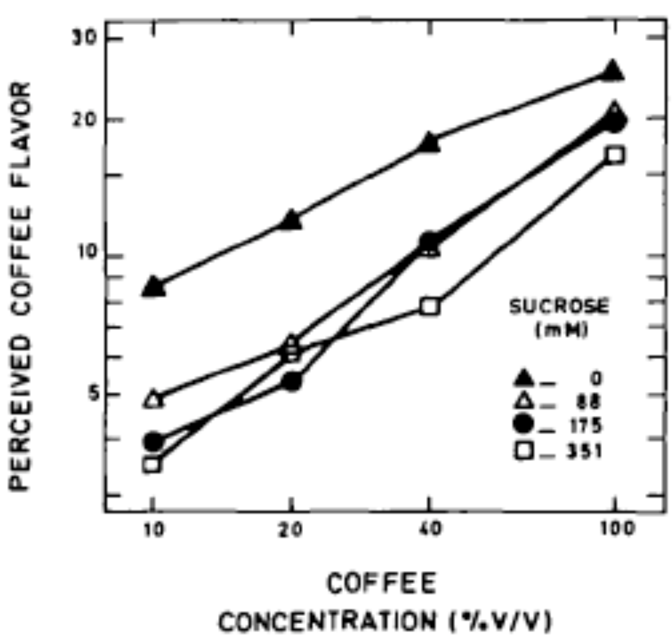


Figure 4. Coffee flavor of coffee-sucrose mixtures as a function of coffee concentration. Flavor of coffee without sucrose is also shown.

Additionally, Dunnett tests, one-tailed for post hoc comparisons (O'Mahony, 1986) were performed to compare the flavor intensity of coffee alone (control condition) with the flavor intensity of coffee-sucrose mixtures. The outcome of Dunnett tests revealed that the coffee flavor intensity of samples mixed with sucrose is significantly lower than the sample without sugar. Such suppressive action of sucrose emerged in ten mixtures and failed to occur in the two remaining mixtures: 100% v/v of coffee with 88 or 175 mM sucrose (Table II). Although the flavor suppression is evident, the flavor intensity of mixtures was perceived by several subjects to be equal to or greater than the flavor of coffee alone. The sum of numbers in parenthesis showed that 12.5% of judgments correspond to simple additivity or enhancement behaviors.

Table II. Percentages of suppression (%) for coffee flavor (Co), sweetness (Sw) and total flavor intensity (TFI)

Co−S (% v/v−mM)	Co (%)	Sw (%)	TFI (%)
10−88	(1) 35.4**	(1) 39.2**	33.9**
10−175	(3) 40.1**	(7) −	(2) 23.1**
10−351	(1) 48.7**	(5) −	28.7**
20−88	(2) 38.3**	(2) 32.6**	(2) 32.3**
20−175	(2) 47.6**	(5) −	(1) 32.7**
20−351	(2) 35.9**	(3) −	(1) 28.0**
40−88	39.6**	(2) 49.1**	38.9**
40−175	(2) 32.8**	(3) 31.0*	(1) 30.5**
40−351	(1) 51.5**	(3) −	39.9**
100−88	(4) −	83.5**	(2) 22.3**
100−175	(2) −	(1) 51.6**	(2) 22.3**
100−351	(1) 31.4**	(1) 54.1**	39.5**

Percentages of suppression significant at $P<0.05$ (*) or $P<0.01$ (**).
Numbers in parenthesis indicate the subjects who showed enhancement or simple additivity behavior.
Percentages of suppression were not calculated when there were no significant differences in the perceived intensity between the mixed and unmixed condition.

Sweetness perception. The plot of perceived sweetness versus sucrose concentration for the twelve flavor-taste mixtures is shown in Figure 5. Sweetness of pure sucrose solutions is also included. To determine the suppressive effect of coffee, the sweetness data (logarithms of the normalized judgments) were evaluated by a repeated measures ANOVA. The results showed a significant effect for sucrose ($F_{(2,26)}$ = 10.9; $P<<0.001$), coffee ($F_{(4,52)}$ =

4.8; P<0.01) and the sucrose by coffee interaction $F_{(8,104)} = 300$; P<<0.001). This effect is reflected in the slopes of the sweetness functions, which show a continuous tendency to steepen with increasing coffee concentration. The slopes and their standard deviations were: 0.44 ± 0.23 for sucrose alone, and 0.80 ± 0.40, 0.72 ± 0.62, 0.94 ± 0.75 and 1.18 ± 0.74 for mixtures of sucrose with a background of coffee ranging from 10% v/v to 100% v/v. Thus, the sweetness intensity of the mixtures containing 40 or 100% v/v coffee increased more sharply with sucrose concentration than did the sweetness of the other mixtures.

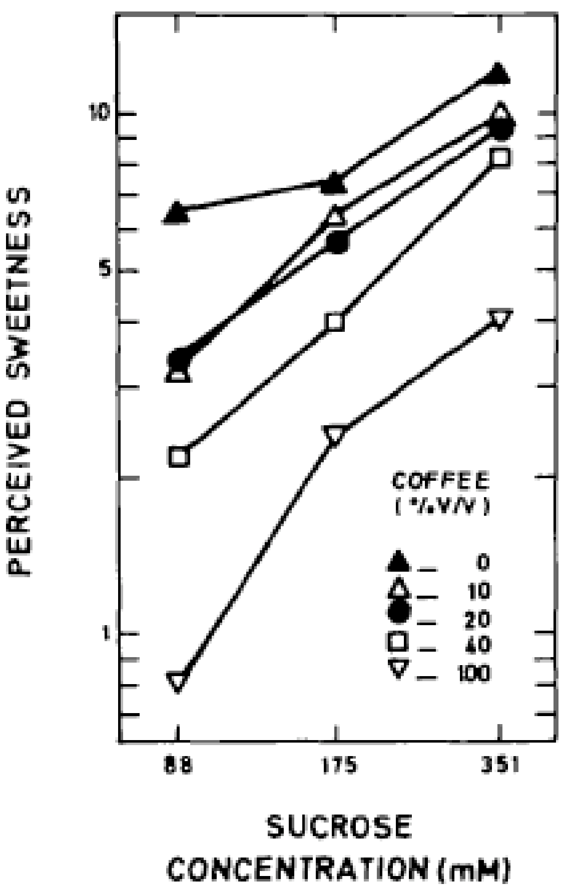


Figure 5. Sweetness of coffee-sucrose mixtures as a function of sucrose concentration. Sweetness of sucrose without coffee is also shown.

Post-hoc multiple comparisons (Dunnett tests) demonstrated that sweetness reduction in mixtures was not always significant. The percentages of suppression (Table II, column of sweetness) indicate that all coffee dilutions suppress the intensity of the lowest concentration of sucrose but that this effect was not always evident for 175 and 351 mM sucrose. For these sucrose concentrations the number of enhancement and simple additivity judgments increase (see numbers in parenthesis). On the average, 20% of judgments revealed an absence of suppression phenomenon.

Total flavor intensity. The total intensity of the flavor-taste mixtures is depicted as a function of coffee and sucrose components in Figure 6 (pictures A and B). TFI functions have a shape very similar to TTI ones. It is of interest to compare the magnitudes of total flavor for the twelve mixtures against the magnitudes of coffee and sucrose estimated alone. Intensity data plotted against coffee dilution exhibit a marked dependence of coffee level. Thus, at lower levels, the mixtures showed greater intensities than estimations of coffee alone but, at higher levels, the opposite occurs (Figure 6A). This was confirmed with a repeated measures ANOVA (on log-transformed estimations). The ANOVA showed highly significant effects for coffee ($F_{(3,99)}$ = 30.6; P<<0.001) and sucrose concentration ($F_{(3,39)}$ = 25.2; P<<0.001), and the interaction was also significant ($F_{(9,117)}$ = 11.5; P<<0.001).

When intensity data were plotted against sucrose concentration the TFI lies always above the estimations of sucrose alone (Figure 6B).

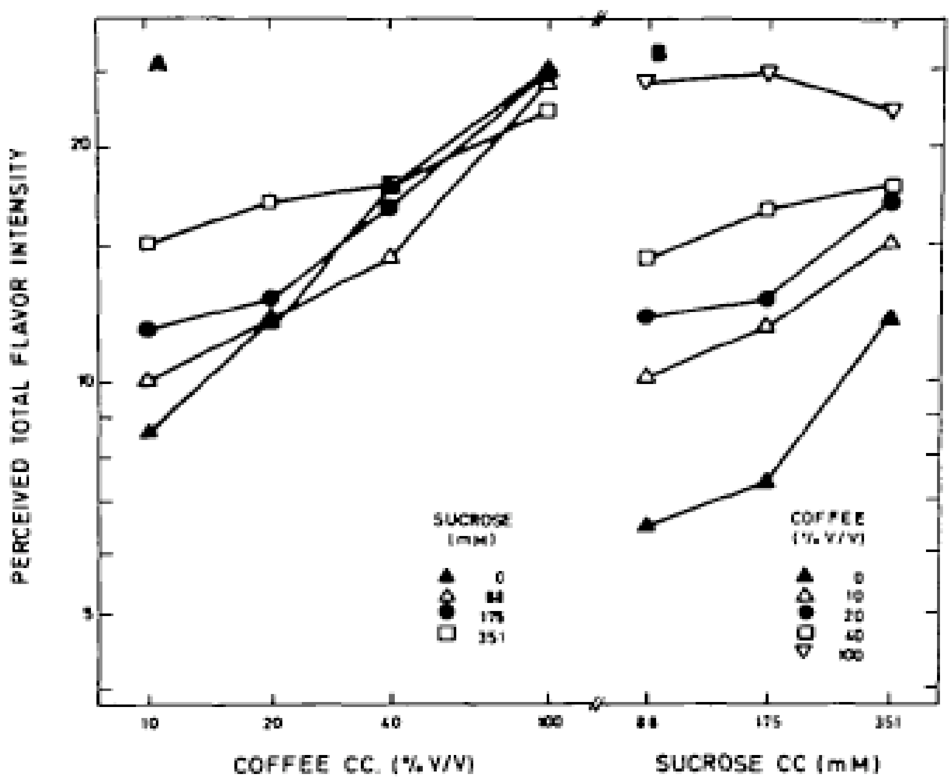


Figure 6. A. Total perceived flavor of coffee-sucrose mixtures as a function of coffee concentration. B. Same data as in A, depicted as a function of sucrose concentration. In both cases filled triangles represent coffee flavor of pure coffee, or sweetness of pure sucrose solutions.

The ANOVA results revealed highly significant main effects for sucrose ($F_{(2,26)}$ = 25.5; P<<0.001) and coffee dilution ($F_{(4,52)}$ = 25.7; P<<0.001), as well as the interaction ($F_{(8,104)}$ = 38.5; P<<0.001). Results obtained by Dunnett tests revealed that below 20% v/v of coffee, the magnitude of TFI exceeds the flavor of coffee alone, but above this level, the opposite effect becomes significant, proving the high degree of suppression that 20, 40 and 100% v/v of coffee produces on sweetness as well as on TFI.

Analyzing percentages of suppression (Table II), the reduction in TFI was evident for all mixtures. Thus, for any given level of coffee or sucrose the percentages of suppression of the TFI appear to be constant (mean suppression value = 33%). Although the overall intensity of the mixtures was, on average, 67% as strong as the simple sum of coffee flavor and sweetness, a few judgments do not show\ suppression behavior (see numbers in parenthesis).

Discussion

The results summarized in Figures 1 to 6 show the mutual interactions between caffeine-sucrose and coffee-sugar mixtures.

Interactions between flavor components accompany our daily perceptual experience. In quantitative terms we speak about chemosensory interactions when perceived intensity of taste-taste and odor-odor mixtures differs from the simple sum of the intensities of the components (Bartoshuk, 1975; Hyman and Frank, 1980a, b). In contrast, previous research has shown that odors can suppress or have no effect on tastes (Gillan, 1983; Murphy and Cain, 1980). Also it was proved that taste-smell interactions are tastant- and odorant-dependent (Frank and Byram, 1988).

Evidence for taste suppression was pointed out in previous investigations, and we may conclude from the present results (Tables I and II) that suppression is the most common finding in our mixtures.

Bartoshuk (1975) proposed that the degree of mixture suppression found for a substance is related to the exponent of the psychophysical function. Consequently, taste substances which have flat individual functions show suppression when they are mixed.

Although several authors claim different values of exponent for the sweetness function (from 0.7 to 1.3), psychophysical power functions with low exponents were obtained for sucrose, as well as for caffeine and coffee solutions estimated alone (García-Medina, 1981; Calviño, 1984, 1986). According to these previous results the sweet, bitter or flavor response to a caffeine-sucrose or coffee-sugar solution may be expected to reflect considerable suppression of perceived intensity.

The suppression for each taste or flavor component may be characterized by analyzing both the exponent of the particular stimulus-response function and the significance of the ANOVA interaction term. Our results showed that functions for bitterness (Figure 1), coffee flavor (Figure 4) and sweetness (Figures 2 and 5) in mixtures were steeper than the ones corresponding to the pure stimuli. Furthermore, ANOVA interaction terms always reached significance giving statistical support to the abatement of perceived intensity depicted at low concentrations and the convergence at high concentrations of the tastant studied. Sensory interactions, proved statistically, indicate a lack of independence. An inhibition or a lack of discrimination between the components was generally postulated as the mechanism underlying perceptual suppression. As Békésy (1967) pointed out, inhibition cancels out a whole group of undesired information and selected information remains at conscious level.

The magnitude of suppression depends upon the quality of the suppressive component in taste-taste mixtures. Kroeze (1980) found that suppression is affected by the degree of similarity between the stimuli: the more similar two stimuli are the more they will suppress each other. It was also shown that a mixture of sucrose and sodium chloride is judged to have a sweet taste which is qualitatively different from that of a mixture of sucrose and quinine sulphate when all taste qualities are together in space and time (Kuznicki and Ashbaugh, 1982)—reinforcing the position of a taste continuum rather than four primary tastes (Schiffman and Erickson, 1980; Erickson, 1982).

An analysis of the present data is useful to note the reciprocal actions of caffeine and sucrose. The comparison of the subjective intensity of both compounds in an unmixed state showed that the subjective intensity of sucrose (S) and caffeine (C) are similar in the middle range of concentration: 292 mM(S) and 13 mM(C), 585 mM(S) and 26 mM(C) (Figures 1 and 2). For these pairs, bitterness was suppressed significantly but sweetness was not affected (Table I). Comparing the few judgments that show no suppression for bitterness with the more frequent judgments of additivity or enhancement for sweetness, we may arrive at the same conclusion: caffeine is more affected by sucrose than sucrose is by caffeine. The above-mentioned asymmetry suggests that sucrose is a better suppressive agent than caffeine. This agrees with the extended use of sucrose not only for its nutritional and hedonic properties but also for its properties of masking bitterness and its resistance to bitter suppressive effect.

The fact that the sweetness of some mixtures showed a great frequency of individual non-suppressive judgments deserves a comment. Although we made no assessment of a possible correlation of these non-suppressive judgments with PTC sensitivity it seems unclear that a taster—non-taster bimodal distribution for PTC affects the degree of sweet suppression, as in the present conditions all subjects tested indicated suprathreshold magnitude to the unmixed caffeine stimuli.

Another explanation for non-suppressive judgments of sweetness may be related to the ability of caffeine to enhance sweetness. However, existing evidence is equivocal (Schiffman et al., 1986; Mela, 1988). Furthermore, neither stimulus presentation nor range of caffeine concentration (mM)—or the type of sweetener in the present work—coincide with those used by Schiffman who reported the enhancement of sweetness of some non-carbohydrate sweeteners.

Neither taste-taste nor taste-odor additivity were addressed in the second experiment. In contrast, subjects were instructed to treat the coffee component of the mixtures as an integral flavor sensation rather than as an analyzable sum of bitter taste and coffee odor. With this task it is possible to know the perceptual processing of flavor-taste pairs.

A first analysis shows that interactions between coffee and sucrose have a tendency similar to the respective mixtures between tastants. Similar judgments for coffee flavor (Co) and sucrose sweetness (S) in unmixed state were found in the middle range of concentration: 10% v/v (Co) and 175 mM (S), 20% v/v (Co) and 351 mM (S) (Figures 4 and 5). For these pairs, there are no reciprocal suppressive actions: coffee flavor is suppressed significantly by sucrose but sweetness is not affected by coffee. Furthermore, judgments of enhancement or simple additivity support the conclusion that sucrose is a better masking agent than coffee. This asymmetric suppressive effect may be ascribed to a decrease of the volatility of coffee produced by the viscosity of the sucrose solutions. However, the intrinsic viscosity of sucrose in the concentration range used here (1 -5 cps) does not affect the diffusion rate of coffee stimuli evaluated at 50°C.

Although a similar suppressive behavior is evident for both taste-taste and flavor-taste mixtures, the interactions between coffee and sucrose produced slightly lower reciprocal suppression than did the caffeine-sucrose mixtures (see columns of percentages of suppression for components in Tables I and II). As noted above, we analyze in the present experiment coffee flavor perception as a unit, but we may consider the mixture between coffee flavor (composite modality of odor and taste) and sucrose (simple modality of taste) as a mixture between modalities rather than within modalities. Under this assumption these results agree with those of Gillan (1983) in which suppression produced by mixtures within modalities, i.e., taste-taste suppression, is greater than suppression produced by mixtures between modalities, i.e., taste-odor.

The question of additivity in this experiment was not faced with the mutual interactions of attributes belonging to different chemosensory modalities. However, the quantitative assessment of the separate effects of the taste and the odor of coffee on sweetness of sucrose and vice versa may be determined in future research. At this point it is strictly conjectural whether the assessment of individual flavor modalities displays the same asymmetric suppressive effects obtained here, where the comparisons of the reciprocal actions were made at similar perceived intensities of the mixture's constituents in isolation.

In contrast to the behavior exhibited by the components, only mixture suppression was observed for total taste (TTI) or flavor intensity (TFI). Furthermore, TTI or TFI show a percentage of suppression which is rather stable irrespective of the mixture (about 30-40%). A small number of judgments of additivity or enhancement across all mixtures evaluated, and a small variation in data dispersion, also support the extended hypoadditivity effect. Thus, looking at Figures 3 and 6, half of the mixtures (with low levels of caffeine and coffee) showed partial addition as in odor mixtures (Cain and Drexler, 1974):

$$\psi_S < \psi_{C-S} < \psi_C + \psi_S$$
$$\psi_C < \psi_{C-S} < \psi_C + \psi_S$$
$$\psi_S < \psi_{Co-S} < \psi_{Co} + \psi_S$$
$$\psi_{Co} < \psi_{Co-S} < \psi_{Co} + \psi_S$$

and the other six mixtures (with high levels of caffeine or coffee) showed compromise behavior:

$$\psi_S < \psi_{C-S} < \psi_C$$
$$\psi_S < \psi_{Co-S} < \psi_{Co}$$

We may conclude that suppression of each component is controlled by the molar concentration of the other component in the mixture but that a loss of about a third part of the total perceived intensity is produced independently of the molar concentration of the components in the mixture.

Although the present results suggest that both quality and intensity of the suppressive component determine the degree of suppression in mixtures, the effect of the instructional context given to the subject may also play a role in the magnitude of suppression. Further research on this issue is needed.

References

Bartoshuk, L.M. (1975) Taste mixtures: is suppression related to compression? *Physiol. Behav.*, **14**, 643-649.

Bartoshuk, L.M. (1979) Taste interactions in mixtures of sucrose with NaCl and sucrose with QHCl. *Soc. Neurosci. Abstr.*, 5, 125.

Bartoshuk, L.M., Rennert, K., Rodin, J. and Stevens, J.C. (1982) Effects of temperature on the perceived sweetness of sucrose. *Physiol. Behav.*, **28**, 905-910.

Békésy, G. von (1967) Sensory Inhibition. Princeton University Press, New Jersey.

Boudreau, J.C, Oravec, J. and White, T.D. (1981) A peripheral neural correlate of the human fungiform papillae sweet, bitter sensations. *Chem. Senses*, **6**, 129-141.

Cain, W.S. (1975) Odor intensity: mixtures and masking. *Chem. Senses Flav*., **1**, 339-352.

Cain, W.S. and Drexler, M. (1974) Scope and evaluation of odor counteraction and masking. *Ann. N. Y. Acad. Sci*., **237**, 279-285.

Cain, W.S. and Moskowitz, H.R. (1974) Psychophysical scaling of odor. In Turk, A., Johnston, J.W. Jr. and Moulton, D.G. (eds), *Human Responses to Environmental Odors*. Academic Press, New York, pp. 1-32.

Calviño, A.M. (1984) La cuantificación del dulzor. J. Inst. Farm. y Bromatol. **7**, 751-761.

Calviño, A.M. (1986) Perception of sweetness: the effects of concentration and temperature, *Physiol. Behav*., **36**, 1021-1028.

Christensen, C.M. (1980a) Effects of taste quality and intensity on oral perception of viscosity. *Percept. Psychophys*., **28**, 315-320.

Christensen, C.M. (1980b) Effects of solution viscosity on perceived saltiness and sweetness. *Percept. Psychophys*., **28**, 347-353.

Cometto-Muñiz, J.E., García-Medina, M.R., Calviño, A.M. and Noriega, G. (1987) Interactions between CO_2 oral pungency and taste. *Perception*, **16**, 629-640.

Cowart, B.J. (1987) Perceived burn and taste intensity of physical mixtures of capsaicin and taste stimuli. In Roper, S.D. and Atema, J. (eds), *Olfaction and Taste IX*, N.Y. Acad. Sci., New York, pp. 245-246.

Curtis, D.W., Stevens, D. A. and Lawless, H.T. (1984) Perceived intensity of the taste of sugar mixtures and acid mixtures. *Chem. Senses*, **9**, 107-120.

Enns, M.P., Van Itallie, T.B. and Grinker, J.A. (1979) Contributions of age, sex and degree of fatness on preferences and magnitude estimations for sucrose in humans. *Physiol. Behav*., **22**, 999-1003.

Erickson, R.P. (1982) Studies on the perception of taste: do primaries exist? *Physiol. Behav*., **28**, 57-62.

Frank, R.A. and Archambo, G. (1986) Intensity and hedonic judgments of taste mixtures: an information integration analysis. *Chem. Senses*, **11**, 427-438.

Frank, R.A. and Byram, J. (1988) Taste-smell interactions are tastant and odorant dependent. *Chem. Senses*, **13**, 445-455.

Frankmann, S.P. and Green, B.G. (1987) Differential effects of cooling on the intensity of taste. In Roper, S.D. and Atema, J. (eds), *Olfaction and Taste IX*, N.Y. Acad. Sci., New York, pp. 300-303.

García-Medina, M.R. (1981) Flavor-odor, taste interactions in solutions of acetic acid and coffee. *Chem. Senses*, **6**, 13-22.

Gillan, D.J. (1982) Mixture suppression: the effect of spatial separation between sucrose and NaCl. *Percept. Psychophys*., **32**, 504-510.

Gillan, DJ. (1983) Taste-taste, odor-odor, and taste-odor mixtures: greater suppression within than between modalities. *Percept. Psychophys*., **33**, 183-185.

Hornung, D.E. and Enns, M.P. (1984) The independence and integration of olfaction and taste. *Chem. Senses*, **9**, 97-106.

Hornung, D.E. and Enns, M.P. (1986) The contribution of smell and taste to overall intensity: a model. *Percept. Psychophys*., **39**, 385-39.

Hyman, A.M. and Frank, M.E. (1980a) Effects of binary taste stimuli on the neural activity of the hamster chorda tympani. *J. Gen. Physiol*., **76**, 125-142.

Hyman, A.M. and Frank, M.E. (1980b) Sensitivities of single nerve fibers in the hamster chorda tympani to mixtures of taste stimuli. *J. Gen. Physiol*., **76**, 143-173.

Izutsu, T., Taneya, S., Kikuchi, E. and Sone, T. (1981) Effect of viscosity on perceived sweetness intensity of sweetened sodium carboxymethyl cellulose solutions. *J. Text. Stu*., **12**, 259-273.

Kroeze, J.H.A. (1978) The taste of sodium chloride: masking and adaptation. *Chem. Senses Flav*., **3**, 443-449.

Kroeze, J.H.A. (1979) Masking and adaptation of sugar sweetness intensity. *Physiol. Behav*., **22**, 347-351.

Kroeze, J.H.A. (1980) Masking in two- and three-component taste mixtures. In van der Starre, H. (ed), *Olfaction and Taste VII*. IRL Press, Oxford, p. 435.

Kroeze, J.H.A and Bartoshuk, L.M. (1985) Bitterness suppression as revealed by split-tongue taste stimulation in humans. *Physiol. Behav*., **35**, 779-783.

Kuznicki, J.T. and Ashbaugh, N. (1982) Space and time separation of taste mixture components. *Chem. Senses*, **7**, 39-62.

Laing, D.G. (1987) Coding of chemosensory stimulus mixtures. In Roper, S.D. and Atema, J. (eds). *Olfaction and Taste IX*, N.Y. Acad. Sci., New York, pp. 61-66.

Laing, D.G. and Willcox, M.E. (1983) Perception of components in binary odour mixtures. *Chem. Senses*, **7**, 249-264.

Lane, H.L., Catania, A.C. and Stevens, S.S. (1961) Voice level: authophonic scale, perceived loudness, and effects of sidetone, *J. Acoust. Soc. Am.*, **33**, 160-167.

Lawless, H.T. (1979) Evidence for neural inhibition in bittersweet taste mixtures. *J. Comp. Physiol. Psychol*., **93**, 538-54.

Lawless, H.T. and Stevens, D.A. (1984) Effects of oral chemical irritation on taste. *Physiol. Behav*., **32**, 995-998.

Mela, D.J. (1988) Caffeine under natural conditions does not alter taste intensity. Abstracts of the X Annual Meeting of the Association for Chemoreception Sciences, Sarasota, Florida, USA.

Murphy, C. and Cain, W.S. (1980) Taste and olfaction: independence vs. interaction. *Physiol. Behav*., **24**, 601-605.

O'Mahony, M. (1986) *Sensory Evaluation of Food. Statistical Methods and Procedures*. Marcel Dekker, New York. p. 211-226.

Schiffman, S.S. and Erickson, R.P. (1980) The issue of primary tastes versus a taste continuum. *Neurosci. Biobehav. Rev*., **4**, 109-117.

Schiffman, S.S., Díaz, C. and Beeker, T.G. (1986) Caffeine intensifies taste of certain sweeteners: role of adenosine receptor. *Pharmacol. Biochem. Behav*., **24**, 429-432.

Stevens, J.C. and Marks, L.E. (1980) Cross modality matching functions generated by magnitude estimation. *Percept. Psychophys*., **27**, 379-389.

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