Detection of a Target Taste in a Complex Masker

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Abstract

Detection thresholds for sodium chloride were compared in aqueous solution, in mixture with a sucrose masker, in mixture with a citric acid masker, and in mixture with both of these maskers together. Separately the two maskers raised the threshold of sodium chloride by three to four times, and together by over nine times, a result consistent with independence (additivity) of the two masking effects. To achieve comparable masking with either sucrose alone or with citric acid alone would require increasing their masking concentrations by about ten times. Hence multiple masking can be a far more efficient means of concealing a taste, whether an unpleasant one (e.g. the bitter taste of medicine) or a pleasant one (e.g. a salty or sweet condiment). Multiple masking has dietary and culinary significance, especially for middle aged and elderly persons concerned about salt intake, because their thresholds for NaCl, whether with or without maskers, are typically two or three times higher than those of youthful persons. **Chem. Senses 22: 529–534, 1997.**

Introduction

This study concerns the detection threshold of a target taste (NaCl): (i) by itself; (ii) in mixture with sucrose, a masker; (iii) in mixture with citric acid, another masker; and (iv) in mixture with the sucrose and citric acid maskers together. The question addressed was whether and to what extent a pair of taste maskers can combine their effects on a target taste, in the sense that detection threshold for the target might be higher in the presence of both maskers than in either masker alone. This question has theoretical and practical relevance.

On the theoretical side is the issue of whether different maskers can combine their effects on a target taste independently of each other. If so, then their effects can be said to be exactly additive; that is, the combined effect of both maskers together would equal the sum of their effects separately. In other words, if masker a elevates the target threshold by factor x, and masker b elevates the target threshold by factor y, then a and b together in mixture would elevate the target threshold by factor $(x + y)$. Alternatively, the effects of the two maskers under mixture could be interactive, making the mixture either hypoadditive (in the extreme, the effect of the two together might be no more than that of the greater masker separately) or hyper-additive (their combined effects in mixture are greater than the sum of their separate effects). How this turns out can help to shape models of how taste masking works.

On the practical side is the degree to which one might hide a taste by means of masking with multiple maskers acting in concert compared with what can be achieved with single maskers. In our laboratory we looked at this question in the context of aging, taste and nutrition. The question was whether age-related loss of absolute sensitivity, reported by many investigators (Byrd and Gertman, 1959; Grzegorczyk *et al.*, 1979; Schiffman *et al.*, 1979; Hyde *et al.*, 1981; Moore *et al.*, 1982; Weiffenbach *et al.*, 1982; Bartoshuk *et al.*, 1986; Stevens *et al.*, 1995; and Stevens, 1996), has any bearing on the ability to taste table condiments like salt and sugar in foods (Stevens *et al.*, 1991). For example, a person (whether young or old) needs about ten times more salt to just detect it in tomato juice than to just detect it in plain water. Presumably this happens because of masking by other tastes in tomato (e.g. acids, sugars). But whether in water or tomato, older subjects need for detection two or three times more salt than do younger subjects. Thus, the amount of salt condiment needed by an elderly person merely to detect its minimal presence in a common food turns out to be a substantial dietary quantity.

Later investigation (Stevens, 1996) of masking in simple binary mixtures of common tastants (NaCl, sucrose, citric acid and quinine hydrochloride) revealed different degrees of simple masking in various pairings of these tastants. (In every pairing, though, the masked threshold of older subjects exceeded that of younger subjects.) Only with very strong maskers was the detection threshold elevated by as much as 10-fold, as it was by the tomato masker. Moderate citric acid and sucrose alone each masked NaCl by only ~3.5-fold. This suggests that the potent masking exerted by tomato may have been achieved by concurrent action of multiple masking substances. Hence the practical side of learning whether sucrose and citric acid together can push the NaCl threshold higher than either of them alone.

Whenever two or more maskers operate together on a target there is the potential that they can also operate on one another, so that their joint effect on the target is difficult to predict. For example, one masker of a target may mask a second masker of the same target, thereby attenuating the second masker's potential effect on the target. (Such an action has been termed 'disinhibition' in other contexts.) In the present experiment the concentrations of the sucrose (0.26 M) and citric acid (0.0034 M) maskers were chosen because they arouse approximately equal (and moderately strong) subjective taste magnitudes, as determined by Bartoshuk *et al.* (1986), and because they were shown by Stevens (1996) to mask NaCl by comparable amounts. We deemed this to be a reasonable starting point for examining complex masking. Detection depends upon a complex interaction between integrative and inhibitory properties (see Stevens, 1997); our present knowledge of these properties allows us to make only modest and tentative predications about the detection of a single element in any complex context.

Materials and methods

Subjects

Seven men and five women served in each of two ~1 h sessions held on different days. Mean age was 20 years (range 19–26). Subjects were non-smokers, paid for participation, and gave informed consent. In one session a subject gave one threshold to NaCl alone and another threshold to NaCl in mixture with both sucrose and citric acid maskers together; in the other session the subject gave one threshold to NaCl in the sucrose masker and another threshold to NaCl in citric acid masker. The order of these two sessions was balanced. The molarity of the two maskers was always the same, whether presented separately or together.

Stimuli

Solutions were made up with Baker's grade sucrose, citric acid and NaCl in deionized water (DHOH). They were prepared at room temperature, stored under refrigeration and warmed to room temperature before testing. The molarity of the maskers was 0.26 for sucrose and 0.0034 for citric acid throughout. One series of 25 molar concentrations of NaCl in 0.25 log steps was made up by serial dilution with DHOH starting from a 1 M mother solution. Three other series of 20 steps each were made up by 20 serial dilutions of a mother solution made up of 1 M NaCl with 0.26 M sucrose or with 0.0034 M citric acid, or with both of these. For these three series, dilutions were made not with DHOH, but rather with solutions containing 0.26 M sucrose or 0.0034 M citric acid, or with both. Because the masked thresholds were higher than in the DHOH only stimuli, fewer concentration steps were needed.

Stimuli were sampled by the sip and spit method, with rinsing of the mouth using DHOH between presentations. On each trial two 30 ml plastic medicine cups were placed in front of the subject, one of which contained ~5 ml of the target stimulus and the other ~5 ml of the masking stimulus (or stimuli) or DHOH only. The subject had to decide which cup contained the salt (left–right position randomized). The subject received no feedback as to whether the choice was correct. Feedback as an option in this experiment was avoided lest a subject's performance be inadvertently tied to possible false bases for responding associated with the clearly perceptible qualitative differences among the solutions tasted.

Psychophysical method

The method combined two-alternative forced-choice with up–down adaptive tracking (Wetherill and Levitt, 1965), using the following rules to generate a track. (i) The first trial began at dilution step 10 (0.0032 M concentration of NaCl). No trial was counted, however, until the subject made one incorrect choice. (ii) Whenever the subject chose incorrectly on a trial the concentration on the next trial was raised; whenever the subject chose correctly on a single trial that same concentration was given again on the next trial; whenever correctly on two consecutive trials, the concentration on the next trial was lowered. (iii) This procedure continued until 10 transitions occurred in the track (from up to down or from down to up); these transitions are sometimes called 'turn-arounds'. (iv) The size of the increase or decrease in concentration along the track equaled two dilutions steps (i.e. one half-log change) up through the third turn-around, after which it was reduced to one dilution step (or one quarter-log change); the intent was to move the track quickly to the neighborhood of the threshold and thereafter to pinpoint the threshold more precisely. (v) Threshold was defined as the mean of the last six transition levels, reckoned in dilution steps. These rules, implicit in Wetherill and Levitt's account of adaptive tracks, were aimed at controlling so-called 'starting biases' associated with starting a track too far away from the desired threshold measurement.

The average track consisted of 28 forced-choice trials (range 15–39) and lasted (not counting instruction and rest period between tracks) 23 min (range 15–30).

Results

Table 1 lists the mean and standard deviation for each type of NaCl threshold; the means are shown both in dilutions steps and in corresponding molarity. The last column in the table shows the factor by which masking on the average elevated the NaCl threshold. This factor is simply the mean masked threshold divided by the mean threshold in DHOH only. For easier visualization results are also plotted in Figure 1, where for each masking condition is plotted the mean threshold, also in both dilution steps and in molarity.

Table 1 Mean (and standard deviation) dilution step of the NaCl thresholds of 12 subjects: in DHOH and in three masking backgrounds; mean threshold expressed in molarity; and masked threshold divided by DHOH threshold to show threshold rise under masking

Masking condition	Dilution steps		Mean molarity	Threshold rise factor
	Mean	(SD)		
DHOH only	11.0	(2.02)	0.00178	
0.26 M sucrose	8.75	(2.23)	0.00649	3.65
0.0034 M citric acid	8.68	(1.67)	0.00676	3.80
Sucrose and citric acid	7.14	(0.941)	0.0164	9.21

Note that the mean threshold masked by sucrose only and the mean threshold masked by citric acid only were approximately equal. This is as expected since the concentrations of these maskers were chosen from the data of Stevens (1996) to give roughly equal amounts of NaCl masking. Neither of these maskers proved nearly as effective separately, though, as both of them together. Accordingly, masking was additive and commensurate with the ~10-fold masking of NaCl by tomato. The idea that total masking might be no greater than that produced by the stronger masker alone is ruled out by the data.

To test the independence of the two masking effects (masking additivity) the results (stated in dilution steps) were subjected to a two-factor ANOVA in which factor A was sucrose (masker versus zero masker) and factor B was citric acid (masker versus zero masker). These factors were significant: for A, $F = 25.84$, $P < 0.0004$, and for B, $F = 12.67$, $P < 0.005$. Their interaction term, however, was non-significant ($F < 1.0$, $P < 0.49$), consistent with a model of independent effects of the two maskers (i.e. complete additivity).

Discussion

The efficacy of multiple maskers is perhaps best seen in the light of the behavior of single maskers. An earlier study of masking (Stevens, 1996) in simple binary mixtures of common tastants revealed various amounts of masking depending on the particular compounds paired, but the impressive feature of that study was actually how well people could detect the weak presence of one target in the

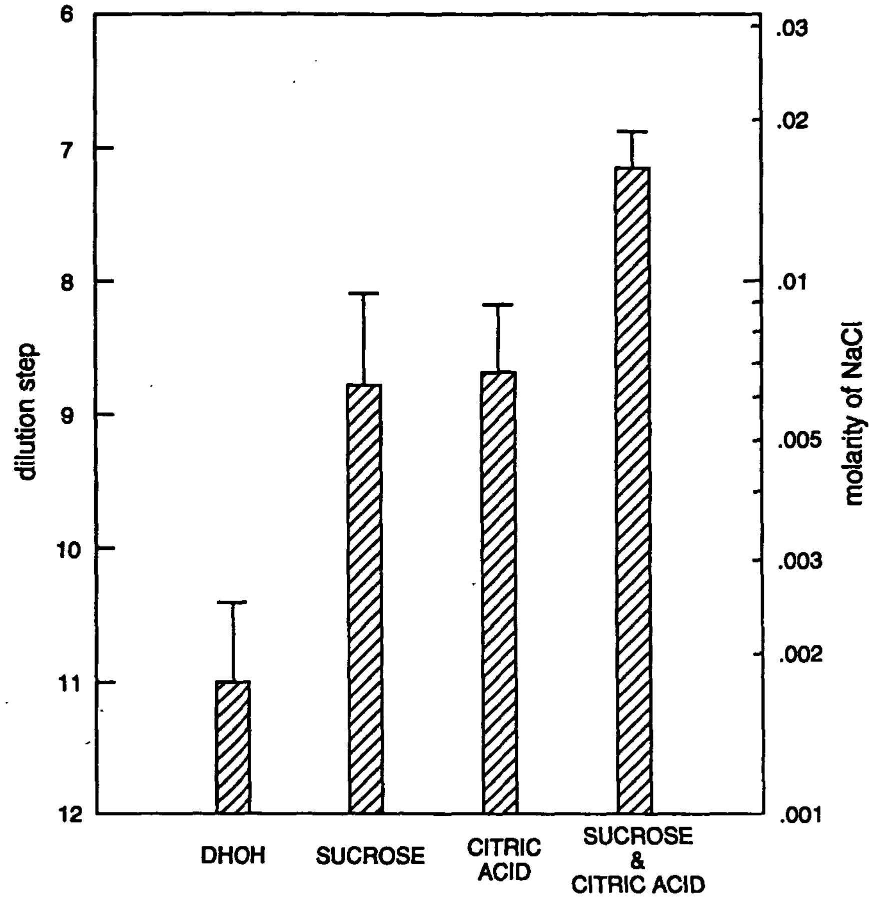

Figure 1 Mean threshold and one standard error, expressed in dilution steps (left ordinate) and corresponding molarity (log scale at right ordinate) in DHOH only, in mixture with 0.26 M sucrose, with 0.0034 M citric acid and in mixture with both 0.26 M sucrose and 0.0034 M citric acid.

presence of another, even rather strong, taste of different quality. Though some degree of masking was revealed by every pair tested (12 altogether), the amount of masking was actually moderate throughout. To eradicate a simple taste by means of another simple taste can be difficult (in the case of some compounds, for all practical purposes impossible). From a psychophysical point of view the channels that mediate different qualities in taste are quite impressively (but not totally) independent of each other.

It now becomes apparent, however, that combining maskers of different quality can provide a considerably more efficient means of eradicating a target taste than simply increasing the concentration of either one of the maskers used by itself. This can be appreciated in the light of Stevens' (1996) measurement of the degree of masking in binary mixtures of NaCl, sucrose, citric acid and quinine hydrochloride. These measurements specify approximately how much the concentration of a masker must be increased in order to offset an increase in the concentration of the target in order to preserve the detection threshold of the target. In the case of the target NaCl in sucrose and citric acid maskers these equations were:

$$[N] = k[S]^{1/0.45} \quad (1)$$

$$[N] = k[C]^{1/0.36} \quad (2)$$

where [N] is the detection threshold molarity of NaCl, and [S] and [C] are the masking molarities of sucrose and citric acid respectively. These power equations tell us that it takes an ever-expanding amount of the maskers to just eliminate the sensation from increasing amounts of NaCl. As shown in Table 1 (right-hand column), the threshold for NaCl was 3.65 times higher in sucrose than in DHOH alone; adding citric acid masker increased the NaCl threshold to 9.21 total, i.e. by a factor of 2.52 (2.52 × 3.65 = 9.21). Now consider how much additional sucrose it would instead have taken to increase the NaCl threshold by that same factor of 2.52. Applying equation (1), this turns out to be $2.52^{1/0.45}$, or a factor of 7.8/1. Similarly the threshold for NaCl was 3.80

times higher in citric acid than in DHOH alone; adding sucrose masker increased the NaCl threshold to 9.21 total, i.e. by a factor of 2.42 ($2.42 \times 3.80 = 9.21$). Consider how much additional citric acid it would take to increase the NaCl threshold by the same factor, 2.42. Applying equation (2), this turns out to be $2.42^{1/0.36}$, or a factor of 11.6/1. Thus it takes a very large increase in the concentration of a single masker (on average ~10-fold) to achieve the same result as combining the two maskers.

There are practical implications. Suppose that one's goal is to eliminate an unwanted taste—say the bitter taste of a medicine. It may be impractical to add enough sucrose for that purpose; however, the addition of a second masker, say citric acid, might do the trick. On the other hand, suppose the target taste is a desired sensory experience—such as the salt condiment in tomato soup. Because of multiple masking the threshold for the condiment is greatly elevated, thereby necessitating a lot of salt (from a dietary point of view sometimes undesirable). We see that masking, and now especially multiple masking, can constitute a hazard for persons of middle and old age. This is true because in at least three different studies of the matter, involving a large number of simple and complex taste mixtures, the thresholds for elderly people have always exceeded those of younger people by factors of two to six times (Stevens *et al.*, 1991; Schiffman *et al.*, 1994; Stevens, 1996). This fact probably accounts for the finding (Stevens *et al.*, 1991) that half of 20 elderly and 20 middle aged subjects tested failed to discriminate reliably the presence/absence of the salt condiment called for in tomato soup made up with a typical cookbook recipe; in contrast, all but one of 21 young subjects passed the test. Thus the threshold comparisons have important implications for the aging individual. Age-related taste weaknesses, earlier dismissed as benign and idiosyncratic, take on new meaning in the light of taste mixtures and masking (for a discussion, see Stevens, 1996).

The multiple maskers in the present experiment were clearly far more effective than their most effective component alone. Indeed, the outcome is consistent with complete independence of the two masking effects. The finding of additivity and especially the greater effectiveness of multiple masking over simply increasing a single masker may provide a key datum for the future construction of models of taste masking. Persuasive models will doubtless require far more information than is currently available. A good model will have to account for mixtures of maskers of unequal potency and the possibility of masking among the maskers themselves, and even the possible 'disinhibition' of the target that could occur under the right choice of conditions. Something of that kind very likely took place in a recent study by Breslin and Beauchamp (1996). A bitter-sweet mixture of sucrose and urea was found to taste less bitter (and more sweet) upon the addition of a salty masker (sodium acetate), an action the authors attributed to disinhibition; Na appeared to suppress urea's bitter masking of sucrose's sweetness.

Like most current studies of taste mixtures, Breslin and Beauchamp's was concerned with suprathreshold masking, and their method was a version of magnitude estimation. Suprathreshold data are often more typical of everyday taste situations, and the data from magnitude estimation are beguilingly easy to gather. Nevertheless, thresholds have a venerable history in the study of sensory processes. They have provided much of the primary data for the study of mixtures in other senses, and when determined by forced-choice they furnish coveted objectivity. Both threshold and suprathreshold studies are valuable in their own unique ways. A comprehensive descriptive model of taste mixtures might well benefit from a synthesis of both kinds.

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