



Detection of Tastes in Mixture with Other Tastes: Issues of Masking and Aging

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Abstract

When one taste (masker) is strong enough, it can completely mask another taste (target) of different quality. How strong the masker must be to do this depends on how strong the target is. As the target concentration is increased, the masking concentration must be increased, too, but in ever-increasing proportion. To quantify the conditions for such complete masking, the target's detection threshold was measured as a function of the masker's concentration, from zero to strong. This was done for 12 binary combinations of sucrose, sodium chloride, citric acid and quinine hydrochloride. The 12 functions generated show that some tastants mask each other much more efficiently than others. Masking gives new insight into the role of aging in taste: older (66–90 years) subjects' thresholds, regardless of masking concentration, always measured a constant factor higher than younger (18–29 years) subjects' thresholds (about two to seven times higher, depending on target tastant). Thus, with increasing level of the masker, the thresholds of young and elderly go up in parallel. Thresholds of tastants in water alone are false predictors of elderly persons' ability to perceive ingredients like salt and sugar condiments in foods, where, because of masking, their thresholds can be several times higher than in water. Age manifested itself relatively mildly in sucrose and citric acid, moderately in sodium chloride, and strongly in quinine hydrochloride. *Chem. Senses* 21: 211–221, 1996.

Introduction

Everyday experience testifies that one taste can mask another. To quantify masking the psychophysicist has two main methods. The first is to measure the amount by which the detection threshold of one tastant is raised by mixing it with another tastant, the masker. Masking in such mixtures can be seen as complete, since the masked stimulus is completely obscured. The second (the more often studied nowadays) is to rate or scale the perceived supra-threshold intensity of a tastant alone and in mixture with the masker. Masking in such mixtures is partial, insofar as the masked stimulus has a perceptual presence, if at a reduced perceived intensity. In the literature, masking is sometimes called suppression or inhibition, but the idea is the same.

The present study concerns mixtures of the first kind (complete masking). It asks, for example, how does the just-detectable concentration of sucrose depend in mixture on the concentration of citric acid, from weak to strong? It also asks the reverse, how does the just-detectable concentration of citric acid depend in mixture on the concentration of sucrose from weak to strong? Altogether 12 such parametric questions are addressed for all 12 possible combinations of four tastants representative of four taste qualities: sucrose (S), citric acid (C), sodium chloride (N) and quinine hydrochloride (Q). These conditions are SC, SN, SQ, CN, CQ, NQ, and their reverses CS, NS, QS, NC, QC and QN, where the first letter of a pair stands for the target, or masked,

compound and the second for the masking compound in the mixture.

Six of these 12 mixture conditions have greater culinary and dietary relevance than the others and were therefore tested more extensively: CN and NC have relevance to tomato preparations (an example explained below), SC and CS to sweetened citric drinks like lemonade, and SQ and QS to sweetened coffee and chocolate. Such mixtures of mutually masking components are well known to the food scientist.

Present interest in masking came about in the context of the aging of the taste sense. People over 60 or so need two to eight times higher concentrations than young adults to detect common tastants like salt and sugar in aqueous solution—a fact once again confirmed in the present study—and the middle aged something in between. (For other examples see Byrd and Gertman, 1959; Grzegorzczak *et al.*, 1979; Schiffman *et al.*, 1979, 1994; Hyde *et al.*, 1981; Moore *et al.*, 1982; Weiffenbach *et al.*, 1982; Bartoshuk *et al.*, 1986; Stevens *et al.*, 1995). In terms of dietary consumption these amounts may seem benign. Age-related weakening of suprathreshold magnitude estimations is even less imposing, though not without still unexplained peculiarities (Bartoshuk *et al.*, 1986). Aging of taste has therefore seemed unimportant to some.

On the contrary, that aging is important to taste is illustrated by the following example. When asked to discriminate the presence-absence of the salt condiment prescribed by a typical cookbook recipe for tomato soup, older persons had real difficulty (Stevens *et al.*, 1991). The results were decisive: 22 of 40 persons of middle and advanced age were unable to discriminate above chance in triangle tests. In contrast, only one of 21 youthful subjects failed the tests. The quantity of salt in these samples was detectable by young subjects and would have been easily detectable in simple aqueous solution by elderly persons. Other ingredients in the tomato soup (e.g. acids and sugars) presumably raised the salt threshold via masking. Indeed, subsequent study showed that, whether young or old, a person needed nearly 10 times stronger concentration of salt to detect it in tomato juice than in water and, whether tasted alone (unmasked) or in juice (masked), the elderly person needs two or three times more salt than the young to detect it. The potential impact of age-associated reduction of taste on food choices and diet is thus easily underestimated without attention to complex taste stimuli more typical of everyday food and beverage consumption.

A prime concern is, therefore, the role of masking in

the evaluation of aging. This concern leads, in turn, to consideration of fundamental psychophysical properties of mixtures and masking in general. The mixtures under study here are the simplest possible ones, having only two components, but it will be argued that even these are more relevant to the question of aging than are lone tastants.

At the onset it is important to distinguish between two kinds of mixtures, whether of tastes, smells or sounds. These were earlier termed 'additive mixtures' and 'subtractive mixtures' (Stevens, 1995), but might preferably be termed 'integrative mixtures' and 'masking mixtures'. On the one hand, when the task is to detect a mixture itself, the components tend to behave integratively, so that together they are detectable in mixture though separately they are undetectable. On the other hand, when the task is to detect one component of the mixture (not the mixture itself) this component (the target) may be suppressed by another component (the masker). Operationally, integration takes place when the subject makes a forced-choice between a mixture and plain water; masking takes place when the subject makes a forced-choice between a target plus masker and a masker alone. Masking seems to characterize mixtures of heterogeneous taste qualities only. In contrast, integration seems to characterize homogeneous and heterogeneous mixtures alike (Stevens, 1995).

The literature on taste mixtures is often equivocal and ambiguous (see, for example, Bartoshuk, 1975, 1978; Geldard, 1972; McBride and Johnson, 1987; Moskowitz, 1972; Pangborn and Trabue, 1967; Pfaffmann *et al.*, 1971), and at least some of the confusion seems to reflect failure to distinguish resolutely between integrative and masking types of mixture by means of appropriate forced-choice methodology.

Materials and methods

Subjects

Because of the time-consuming nature of the experiments (altogether 1920 thresholds are represented here and at least 1000 h of testing) the experiments were conducted over 4 years; and because of formidable demands of stimulus preparation and storage, they were performed one after another with respect to mixture conditions. This meant also that different groups of subjects served for each of the twelve kinds of binary mixtures mentioned. However, for each kind (e.g. SQ, CN or NC) the same group of subjects served throughout.

For mixtures of C and N, S and C, and S and Q there

were eight masking concentrations (including one zero concentration) and, for each, 15 young and 15 elderly adults served. Each subject gave two thresholds on each of four different testing days. The order of masking concentrations was balanced across subjects.

For mixtures of S and N, C and Q, and N and Q there were four masking concentrations (including one 0) and, for each, 10 young and 10 elderly adults served. A subject gave two thresholds on two different days, again with balanced orders of concentrations.

For each tastant the range of masking concentration spanned about 1.7 to 2.7 log units (about 45–450-fold concentration range), covering a sizable chunk of the dynamic range of the masker from weak to strong. To give some inkling of their strength, the strongest concentrations of maskers C, N and Q approximately matched the loudness of a noise at 80 db SPL (Bartoshuk *et al.*, 1986). However, the masking concentrations of S were lower (strongest concentration matched about 60 db SPL). The reason for this difference was the concern that the viscosity of higher concentrations of S could potentially serve as a spurious basis for forced-choice detection.

Altogether 109 young persons (18–29 years) and 49 elderly persons (66–90 years) served, many for multiple kinds of mixtures. However, the age compositions for the 12 mixture types were uniform: mean age ranged from 22.0

to 25.6 and from 75.2 to 77.5, and the standard deviation from 1.3 to 3.6 and from 5.0 to 7.0 for the young and older subjects, respectively. The young subjects were 55 men, 54 women; the elderly were 16 men, 33 women, reflecting availability. For the young subjects there was no evidence of gender differences in any of the conditions. For the elderly only, women yielded some significantly lower thresholds for Q in N and Q in S, and lower (but shy of significantly so) for Q in C. Conclusions regarding both age-associated differences and the nature of masking remained the same, however, under analyses performed with and without the data of the relatively small number (two to four) of male elderly subjects.

One condition of the study, NC, was performed twice. The first version, portions of which were cited in earlier publications (Stevens *et al.*, 1991; Stevens and Cain, 1993) differed significantly from the others in terms of protocol. For one thing, different subject groups performed at different masking concentrations; for another (more important), it became evident that the range of available concentrations of N was restrictive and induced a 'basement' bias at some masking concentrations. For this reason the entire condition was repeated under the protocol used for all subsequent conditions. The effect was to clarify certain puzzling aspects of the first version.

Subjects gave informed consent and received payment for

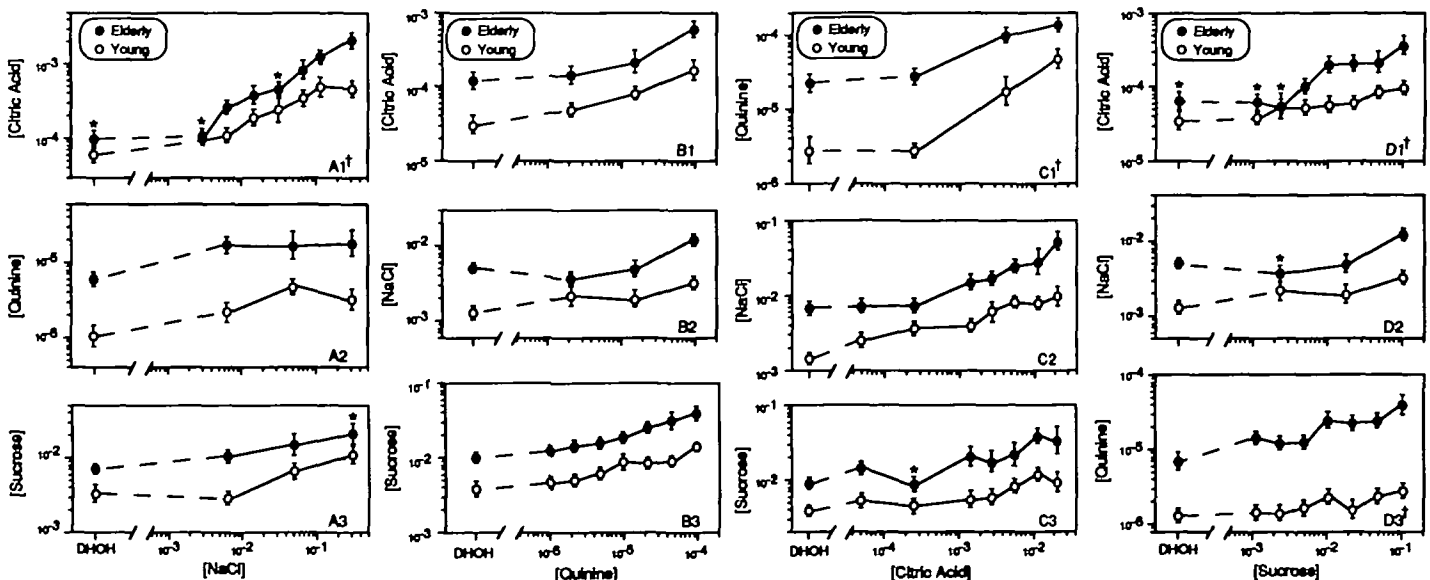


Figure 1 Threshold concentration (ordinates) of the target (masked) tastant as a function of the concentration of the masking tastant (abscissas). The points are geometric means of the thresholds for young and elderly subjects separately. Error bars represent ± 1.0 standard error. Nine young-elderly differences (out of 72 shown) that were not significant by *t*-test are indicated by asterisks (see A1, A3, C3, D1 and D2); the other 63 were significant. The crosses (A1, C1, D1, D3) indicate conditions that by ANOVA gave significant interaction between age group and concentration variables (see text). In each panel the points at the extreme left represent thresholds in DHOH alone (zero masker). Note that the three panels of each column of the figure have the same abscissa, i.e. the same masker. All values are given in molarity.

participation. All reported good or excellent health, were living independently at home, and were able to come to the laboratory or to a senior citizens center for testing.

Stimulus materials

Solutions were stored under refrigeration immediately after preparation, removed and warmed to room temperature before testing, and discarded after 2 weeks. The solutes were Baker grade sucrose (S), sodium chloride (N), citric acid (C) and quinine hydrochloride (Q); the solvent was deionized water (DHOH).

In the course of the study for each solute a series of 15 concentrations was made up by serial dilution in 14 steps of 0.25 log units each (ratio of 1.78 to 1 between steps), thereby furnishing a range of 3.5 log units or 3162/1. Starting concentrations were: for S, 1.0 M; for N, 1.0 M; for C, 0.01 M, and for Q, 0.001 M. These four sets comprised the molar concentrations for the 'unmasked' or simple thresholds in DHOH only. Sixty similar sets of 15 molar concentrations each were also made up in mixture with a fixed molar concentration of a masking stimulus; altogether there were 60 such masking stimuli (shown in the abscissas of Figures 1 and 2). In practice these series were constructed using starting concentrations 1.111 (i.e. 10/9) times greater than their unmasked counterpart, resulting in a transition set whose molarities are all 1.111 times greater than their desired molarity in mixture with the masker. These transition sets were mixed (nine volumetric parts each) with a masking solution (one volumetric part each) made up at 10 times its desired molarity in the mixture. The result is a series having the desired fixed molarity of the masking substance and the same 15 molar concentrations used for the unmasked series (i.e. 9 parts of $1.111 \times$ concentration of substance 'a' + 1 part of $10 \times$ concentration of substance 'b' = 10 parts of mixture solution with the appropriate molarities of the constituents).

Psychophysical method

The method was a two-alternative forced-choice version of up-down tracking (Wetherill and Levitt, 1965). For a given track, on each trial the subject had to decide between two 30-ml plastic medicine cups, one of which contained about 5 ml of the masking stimulus only (or DHOH for zero masker), and the other about 5 ml of the mixture of the target stimulus and the masking stimulus as to which of the two seemed to contain the target (named at the start of the track by the experimenter as sweet, sour, salty or bitter, for S, C, N and Q threshold tracks, respectively). The subject

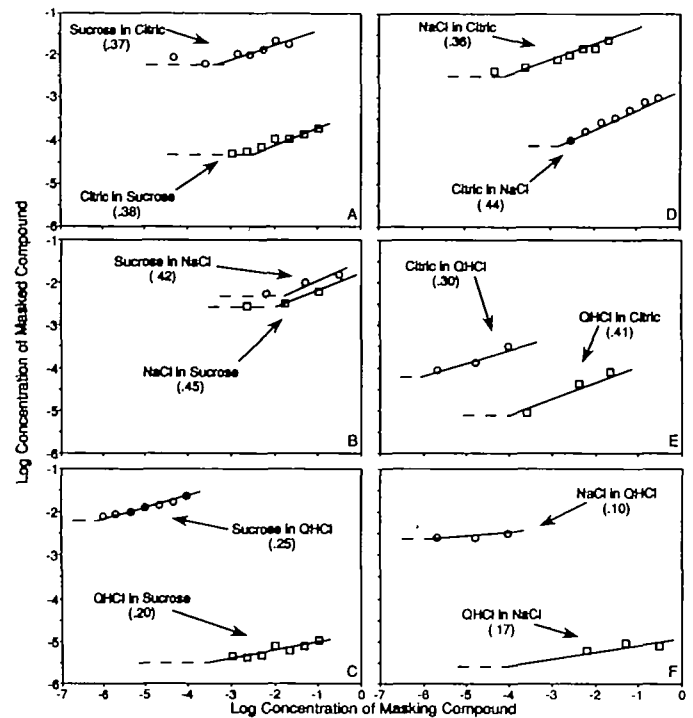


Figure 2 Threshold concentration of the target tastant (ordinates) as a function of masking concentration (abscissas). The points are geometric means of all subjects. The dashed lines mark the thresholds in DHOH alone (zero masker). The solid lines show how the masked threshold rises with concentration of the masker, their slopes are given in parentheses. Note that each panel of the figure shows how a given substance masked another and the reverse. For example, panel A shows how citric acid masked sucrose (top) and how sucrose masked citric acid (bottom).

was not told whether the choice was correct (no feedback, except with a few practice trials before the track began). The instructions were first read by the subject, then paraphrased by the experimenter to ensure comprehension. Each time, the two cups were placed in front of the subject, in random left-right order as to target and non-target. The subject rinsed vigorously with DHOH at the start of the testing and after each sampling (whether target or non-target solution). Contents were always spat out after sampling.

Note that the thresholds generated by this procedure may be thought of as detection thresholds for one component in the presence of another; they are not strictly speaking the same as so-called 'recognition thresholds', in that the subject was not required to name the quality of the target but rather merely to state which of two tastes contained a target.

Four rules governed the generation of a threshold track.

1. The starting concentration was always the tenth dilution step for the young subjects and the twelfth step for the elderly subjects. This difference represents the approximately three-fold average threshold differences between Bartoshuk *et al.*'s (1986) young and elderly subjects tested on the same

four tastants. Exact starting level is not, however, crucial; a similar young-elderly difference resulted when the starting level was the same for both groups (Stevens *et al.*, 1995).

2. No data were counted for a track until the subject erred on a trial. This rule is recommended by Wetherill and Levitt (1965) for reducing potential bias associated with starting a track at a level too remote from the threshold. This rule was instituted after the data for the first three conditions had been taken (SC, CS and CN) and it had become clear that some starting bias was operative (see next paragraph).

3. The choice of concentration followed the rule: 'one incorrect—up, two correct—down'. That is, whenever a subject erred on a trial the concentration on the next trial was incremented by one step (i.e. decremented by one dilution step). Whenever a subject chose correctly the same concentration was presented again on the next trial, and if the subject chose correctly again then on the next trial the concentration was decremented by one step (i.e. incremented by one dilution step). This rule steers the track toward stimulus levels that produce 71% correct responding.

4. Tracks continued this way until seven transitions had occurred in the direction of the track from higher to lower or from lower to higher concentration. This took from about 15–40 trials, typically about 25.

In tracking methods, potential biases frequently show up in upward or downward drift from the start to the end of the track. For this reason we routinely plotted the transition level (of each subject and the mean across subjects) as a function of transition number from start to finish. These revealed in the first three conditions (SC, CS and CN) some drift at the start of some of the tracks. To be on the safe side threshold was defined as the mean of the last two transition concentrations only. The subsequent nine conditions revealed no such drift, after instigation of rule No. 2 above, and so threshold was defined as the mean of the last six transition concentrations. Repeated analyses of the data under different rules show that exact definition of the threshold is not, however, crucial to the conclusions reached but is rather a matter of refinement.

Statistical treatment

The dependent variable in all experiments was the threshold of the target expressed in molar concentration. Statistics on these thresholds were computed geometrically, reflecting normal practice in the study of the senses in general and the chemical senses in particular (Stevens, 1995). That is, one first computes the logarithm of the threshold concentrations, then their mean and standard deviation, and finally,

the antilogarithms of the mean and standard deviation. This is equivalent to computing arithmetic statistics on thresholds expressed in terms of dilution steps (these steps representing concentration ratios) and converting the results (e.g. means and standard deviations) into molar concentrations.

Because different (but partially overlapping) subject groups served in the 12 kinds of pairings of the four compounds and because for any one kind of such pairing the same subject group served throughout at all concentrations of the masker, a single overall analysis of variance or covariance was impractical. Instead, 12 separate two-factor/repeated measures ANOVAs were computed for the 12 pairings of the four compounds, S, N, C and Q, operating on the threshold concentrations expressed in dilution steps. The purpose was to test the effects of aging, masking concentration, and their possible interaction for each pairing of compounds.

Results

DHOH (non-masked) thresholds

Table 1 lists the (geometric) mean threshold for groups of young subjects only for each of the four tastants in the present study and in two earlier ones (Bartoshuk *et al.*, 1986; Stevens, 1995); agreement among them is good. Means from the present study are also given separately for young and elderly subjects. For each tastant the mean threshold was higher for the elderly than for the young, by a factor of 6.2 for Q, 4.4 for N, 2.4 for S and 2.3 for C. These differences were assessed by unpaired *t*-tests on the mean DHOH thresholds for younger and older subjects from all three conditions in which a given compound served as the target; when a particular person contributed more than one threshold his/her mean threshold was used for the computation of *df*, *t* and *P*; for Q, N and S, $P < 0.0001$; for C, $P < 0.0025$.

Masked thresholds

In Figure 1 are plotted, for young and elderly subjects separately, the (geometric) mean threshold of the masked tastant as a function of the concentration of the masking tastant, from weakest (zero masker or DHOH only) to strongest.

The data are organized into four sets of three panels each, one set for each of the four tastants serving as masker (common abscissa) for the other three (three separate ordinates), in order to show that a given masking tastant can exert quite different masking effects on different tastants.

Table 1 Grand average of DHOH thresholds (millimolar concentration) for NaCl (N), sucrose (S), citric acid (C) and quinine hydrochloride (Q) as measured in the present study and two earlier ones by Stevens (1995) and by Bartoshuk *et al.* (1986), as estimated from Figures 2–5, p.54.

		N	S	C	Q
Present study	All	2.7	5.8	0.062	0.0040
	Elderly	5.7	8.9	0.094	0.0099
	Young	1.3	3.7	0.041	0.0016
Bartoshuk <i>et al.</i> (1986)	Young	0.9	2.	0.02	0.001
Stevens (1995)	Young	0.9	5.3	0.032	0.0016

Compare, for example, in Figure 1A, what effect the same (strongest) masking concentration of N (extreme right) had on the thresholds for C, S and Q compared with respect to their DHOH thresholds (extreme left). The same concentration of N raised the threshold of C by nearly 13-fold (averaging younger and older subjects), but the thresholds of S and Q by only three-fold. (These differences between the effects on C and on S and Q proved significant by unpaired *t*-tests at $P < 0.0001$.) Similarly, in Figure 1B the same strongest concentration of Q raised the threshold of C more than five-fold, that of S four-fold, that of N only 1.7-fold—hardly at all. (The differences between S and N, and C and N also proved significant by *t*-tests at $P < 0.0001$.) These figures give some idea of the degree of masking to be encountered in binary taste mixtures. At the highest masking concentrations all 12 target concentrations were highly significantly elevated compared with their respective DHOH thresholds, and for a given masker, some of the elevations were significantly greater than others, as illustrated in the examples cited.

Aging's impact

Figure 1 demonstrates also that the mean thresholds of the older subjects were for all 72 comparisons higher than those of the younger subjects. (Of 72 *t*-tests, 63 were individually significant at $P < 0.0001 < 0.05$; the nine that fell short are marked by asterisks in Figure 1.) The younger-older differences are also shown in the 12 ANOVA's in Table 2. Each of the 12 gave a significant age effect, and 11 of the 12 gave a significant effect of masking concentration. Four of the 12 gave small but significant interactions between age group and masking level (see Table 2 and Figure 1, panels A1, C1, D1 and D3). If the pairs of functions in Figure 1 lay perfectly parallel to each other, then we would strictly speaking expect no such interaction.

Table 2 ANOVA (two-factor, repeated measures) for 12 pairings of C, N, S and Q. Variable A: age group. Variable B: repeated threshold measures under four (Group 1) or eight (Group 2) masking concentrations. Variable AB: interaction of A and B

	A	B	AB
Group 1			
CN	0.0075	0.0001	0.0023
CS	0.0030	0.0001	0.0115
NC	0.0001	0.0001	0.3422*
QS	0.0001	0.0001	0.0132
SC	0.0001	0.0001	0.8151*
SN	0.0001	0.0001	0.9087*
Group 2			
CQ	0.0017	0.0001	0.7048*
NQ	0.0001	0.2303*	0.6016*
NS	0.0002	0.0001	0.1082*
QC	0.0001	0.0001	0.0050
QN	0.0001	0.0001	0.5458*
SQ	0.0002	0.0001	0.5762*

Non-significant results are marked with asterisks. For each A, d.f. = 1; for each B and AB in Group 1, d.f. = 7, Group 2, d.f. = 3.

With only minor exceptions, then, the functions for young and elderly do lie parallel to each other. This means that no matter how much masking elevates the threshold, the average elderly person always ends up approximately a constant multiple higher than that of the average young person. Thus, the aged subject's ability to detect substances like salt and sugar is impaired not only at the low levels needed in plain aqueous solution but also at the much higher levels needed in mixtures that are more realistic approximations to foods.

That aging elevates the threshold of masked and unmasked thresholds alike was also the finding of a recent study by Schiffman *et al.* (1994) on the masking of bitter compounds by sweet ones; elderly subjects' bitter thresholds averaged some five times higher than young subjects'.

Figure 1 shows also that aging can impair the perception of some tastants more than others, whether alone or in mixtures. This is particularly striking in the case of Q, which consistently shows the widest separation between young and elderly subjects (see A2, C1 and D3 in Figure 1). The ratio of the average elderly to the average young threshold concentration over all conditions was 7.25/1 for Q, 3.60/1 for N, 2.71/1 for S and 2.43/1 for C.

Form and slope of the masking function

In order to examine better the nature of masking, the thresholds of all of the subjects, younger and older together, were averaged and these averages plotted in Figure 2, here in six panels, each of which compares the masking of one compound on another and its reverse (e.g. S on C and C on S, as in Figure 2A). Here, it can be seen that in log-log coordinates the masked threshold concentration plots reasonably well as a straight line function of the masking concentration, making allowances that very weak masking concentrations sometimes failed to exert noticeable effect. Masking functions in audition and analogous glare (contrast) functions in vision have often been similarly described (Miller, 1947; Fletcher, 1953; S.S. Stevens, 1966). The solid line segments fitted to the data points in Figure 2 are an attempt to estimate the slope of each masking function as well as the concentration level at which the masker seems to begin to exert some masking effect; the horizontal dashed segments mark the location of the DHOH thresholds. Inevitably, this kind of curve-fitting involves a degree of personal judgment. Given this caveat, the following features of the masking functions in Figure 2 are noteworthy.

1. In any panel of Figure 2 there is little evidence of a slope difference between the members of a pair. In this sense gustatory masking is, at least to a first approximation, symmetrical. In contrast, auditory masking is often radically asymmetrical (a low-frequency tone masks a high-frequency tone more than vice versa), producing a pair of masking functions like those of Figure 2, but having different slopes—even greatly different slopes when the two components differ greatly in frequency (Fletcher, 1953).

The data in Figure 2 do not preclude small asymmetries, however, and one must hold open the possibility that greater asymmetry could characterize other pairs of compounds than those used here and also suprathreshold taste magnitudes more than thresholds. One such study (McBride and Johnson, 1987) of suprathreshold magnitude claimed that S masks C much more than C masks S; another (Schifferstein and Frijters, 1992) that N masks Q much more than Q masks N. Reports of other, less profound suprathreshold asymmetries have come up from time to time.

2. Although the slopes of the masking functions in Figure 2 vary from one pair of tastants to another, they average out to only about 0.3 and are always far less than unity. This signifies that gustatory masking is never very potent, not at least as compared to typical auditory masking (e.g. tone masked by white noise) for which the slope is 1.0. This means that the ratio of the masker (noise) to the

signal (tone) is constant with the level of the signal. In taste, as the signal (masked tastant) increases, the ratio of the masker to the masked tastant must be ever increased in order to erase the signal completely. It is hard to get rid of a taste completely by masking, and the greater the taste to be got rid of the more massive must be the assault on it. Despite the reality of masking, gustation is thus impressive in its ability to preserve the qualitative identity of the components in a mixture. If this were not so then all foods would present only a single taste—that of the strongest component.

It is of interest to note that self-masking functions also have slopes of 1.0, under the assumption that Weber's law of intensity discrimination holds true for S, N, C and Q. If the compound were to serve as both masker and target, then under the usual measurement protocol the subject could distinguish them only on the basis of intensity. According to Weber's law this means that the target concentration would have to increase in simple proportion to the masker. By comparison to self-masking, cross-quality masking is seen to be mild.

3. Some pairs of tastants mask each other more readily than do others, however, judging by the variation of slope from panel to panel in Figure 2. In this regard NQ and QN are remarkable for their virtual inability to mask each other (masking slope equal to 0.1 and 0.17). A masking slope of 0.15 would mean that if the just-masked signal concentration is doubled the masking concentration must be augmented a hundred-fold (as it was, approximately in the experiment) to preserve complete masking ($0.15 \times \log 100 = \log 2$). This is the extreme, of course. More typically (for slope = 0.3) when the signal is doubled the masking concentration must be increased only 10-fold.

The general equation of the masking functions in Figure 1 relating the molar concentration T of the target to that of the masker M may be written (in log and non-log versions):

$$\log T = \alpha \log M + \log k, \text{ and } T = kM^\alpha \quad (1)$$

where the coefficient α (exponent) varied in the extreme from 0.1 for NQ to 0.45 for NS, and is more typically about 0.3. Conversely, equation 1 may be rearranged to show that as the target concentration to be concealed is increased, the concentration of the masker needed to do so must be augmented by ever-increasing amounts:

$$\log M = \alpha^{-1} \log T + \log c, \text{ and } M = cT^{\alpha^{-1}} \quad (2)$$

where the coefficient α^{-1} (exponent) varied in the extreme from 10 for NQ to 2.2 for NS, and is more typically about 3.3.

Overall, Figures 1 and 2 imply that degree of masking (or degree of resistance to masking) is not a property specific to the particular tastant but rather to the combination of the two tastants in mixture.

Discussion

In an account of sweet-sour mixtures McBride (1989) emphasized the central role played by mixtures in the everyday taste world, stating:

Taste psychophysics has traditionally been concerned with the psychophysical functions of *single* stimuli—for example, how does sweetness vary with sucrose concentration? This is understandable, indeed, logical as a first step, but such studies have little ecological validity: people do not drink solutions of sucrose in water, nor solutions containing any other single taste... For taste psychophysics to accrue genuine usefulness outside the psychological laboratory, it must come to grips with the perception of *taste mixtures*. (p.265)

Taste masking and the aging person

McBride's evaluation takes on new meaning in the light of the present investigation of masking and aging. It has been erroneously repeated that aging's impact on human taste is minimal or even absent. Thus, in a symposium on aging of the chemical senses Bartoshuk (1989, p. 65) concluded that '...whole-mouth tasting appears to be essentially normal in the elderly'. In a similar vein, in a news article in *The Journal of NIH Research*, J. Steinberg (1995, p.32) writes that 'Overall, normal aging does not cause loss of taste sensation' and 'Older individuals report loss of taste more often than younger people, but it is often due to olfactory loss or a change in the social context of eating'. In reality, aging does weaken taste, if not as profoundly as it does smell; nevertheless, it does weaken in virtually everybody and on the average by amounts that do matter to everyday life. The cited failure of elderly subjects to discriminate between salted and unsalted tomato soup (Stevens *et al.*, 1991) speaks to this fact; so do the masking thresholds obtained in the present investigation.

The mistaken belief that taste escapes aging's impact stems from two sources, as follows.

Unreliability of brief threshold tests

Most investigations of absolute thresholds, as listed above in the introductory section, convey the impression that sensitivity losses are sporadic and perhaps more often absent

than present in the individual aged person. Bartoshuk *et al.* (1986) posited that mild chronic dysgeusia, often dentitional in origin, might account for these idiosyncratic threshold elevations. In fact, it can and has been shown that nearly every elderly person suffers some loss of sensitivity, not only in taste, but also in smell and touch, and that failure to measure loss in an individual aged person is a matter of poor test-retest reliability resulting from inadequate sampling (Stevens and Dadarwala, 1993; Stevens *et al.*, 1995). One straightforward way to capture individual sensitivity more reliably is to measure an individual's threshold four to six times and take the average. For an individual aged person such an average nearly always reveals weakness in taste, smell and touch, relative to the average young person.

The ubiquity of taste loss with age emerges again in the outcome of the present study. That loss characterizes the individual, as well as the group shows itself in the average individual thresholds to a given tastant obtained under its various maskers. For the combinations studied more thoroughly (NC, CN, SQ, QS, SC, CS) there were eight such thresholds (including zero masker) to be averaged from each of 30 Ss. For others (NS, SN, CQ, QC, QN, NQ) there were four such thresholds (including zero masker) from each of 20 Ss. Altogether there are for each age group 160 such aggregate thresholds representing individual sensitivities (reciprocals of thresholds) to the four tastants. Of the 160 of these for the elderly subjects 154 fall below the average corresponding aggregate for the young subjects. In other words, nearly every elderly individual person revealed weaker sensitivity than the average young person. When it comes to Q the cleavage between youth and elder is radical: 31 of 35 elders' aggregate sensitivities were worse than all 35 of the young.

Further evidence that age-related loss of sensitivity is a more common phenomenon in aging than has been heretofore claimed came recently in a report by Matsuda and Doty (1995) that most of 12 elderly persons (between 70 and 79 years) were unable to detect NaCl stimulation of circumscribed areas of the tongue; the deficits were described as profound.

Use of 'pure' tastants

The down-playing of aging's impact on taste rests in part on the seemingly small quantities of tastants involved. The absolute thresholds for such 'pure' stimuli as salt and sucrose in water solution are too small to matter much, even if aging on the average elevates their thresholds by two- or three-fold.

In addition, Bartoshuk *et al.*'s (1986) measurements of

suprathreshold taste magnitude by magnitude matching to loudness of noise indicated that the tastes of N, S and C were judged of equal strength by young and elderly subjects; high levels of Q were judged weaker by the elderly, low levels stronger. Other investigations (Cowart, 1983; Hyde and Feller, 1981; Murphy and Gilmore, 1989; Stevens *et al.*, 1984; Weiffenbach *et al.*, 1986) have corroborated these findings, sometimes reporting mild losses to C, as well as larger losses to bitter (caffeine, Q). The argument has been that threshold changes have little to say about suprathreshold magnitude.

That suprathreshold magnitude can remain intact in the face of threshold elevation is a commonplace feature of presbycusis and may apply to aging taste as well. However, the supposition that suprathreshold solutions of single tastants, such as N, C, S and Q (and others), are realistic exemplars of the everyday taste world is false. Foods and beverages comprise hundreds of potentially relevant components. The constituents are often able to mask one another, completely or partially, thereby mutually elevating their respective thresholds and diminishing their suprathreshold magnitudes. In the case of tomato juice cited above (Stevens *et al.*, 1991) the threshold concentration for N was nearly 10 times higher in the juice than in water, suggesting much masking.

Masking and food tastes

Masked thresholds of the kind presented here explain why older subjects were unable to detect the salt in tomato soup that was detectable by younger subjects. Masked thresholds can thus provide useful, objective guidelines on the use of condiments like salt and sugar in food concoctions. Condiments play multiple roles in foods. For one thing, they contribute a welcome note to an otherwise bland experience. For another, they can help to mask or partially mask an otherwise unpleasant experience. Thus, the salt in tomato soup, and the sugar in lemonade and chocolate are welcome not only because of the pleasant note they add to the complex, but also because they are able to mute the otherwise unpleasantly strong sour and bitter components. The thresholds measured here can provide some minimal guidelines. They tell us, for example, that it is difficult to suppress the bitter taste (of Q) by adding salt (sugar works better). On the other hand, salt and sugar alike can serve to suppress sour.

Masked thresholds tell us also that common condiments can go just so far in suppressing tastes, fortunately, indeed, in terms of personal safety. The flatness of the masking functions in Figure 2 speaks to the difficulty of erasing

sensations by masking. No amount of sugar or salt may suffice to eliminate or even reduce sufficiently unwanted sour or bitter. In the practical world of the food scientist it may sometimes be more realistic to reduce the unwanted components in other ways. It is impractical, for example, to make lemon juice palatable by adding enough sugar. However, McBride and Johnson (1987) refer to a method for removing by chemical adsorption the acid molecules from lemon juice, thereby rendering it palatable with reasonable sweetening.

Integrative and masking processes in taste

In complex gustatory mixtures, as in auditory mixtures, the components can reinforce and weaken each other at the same time. Mixtures are more detectable than are their separate components, and this is true even when the components have different qualities. (Stevens, 1995). Suprathreshold mixtures generally have greater overall strength or 'impact' than their components tasted alone. At the same time the components of the mixture partially mask (suppress) one another. For this reason it is universally reported that taste mixtures are 'hypoadditive'. By this is meant that the sum of the magnitude estimates (or similar kinds of scaling quantities) of the components tasted separately always exceeds the sum of the magnitude estimates of the components tasted in mixture.

Taste scientists are striving for a theory or model that will adequately describe the nature of summation and masking as revealed by suprathreshold scaling experiments (see, for example, Frijters and DeGraaf, 1989; McBride, 1989; Schifferstein and Frijters, 1993). The efforts are laudable. The various competing schemes sometimes seem premature, however, given the limited archival data with which to work. A comprehensive model should incorporate both threshold and suprathreshold measurements. The challenge may be formidable because as measured by thresholds mixtures are described in stimulus terms, but as measured by scaling they are described in response terms (usually numerical assignments).

We need to know, too, about a larger variety of tastants. It is hardly self-evident that the masking functions depicted in Figure 2 will apply in particulars to other representatives of the same qualitative class. Schiffman *et al.*'s (1994) study of masking of various bitter substances by various sweet ones suggests that the degree of masking (whether by threshold or supra-threshold measures) depends on the particular combinations of sweet masker and bitter target. Nevertheless, we need to know more about the possible

relative contributions of qualitative class and particular compound both as an end in itself and to provide the physiologist with useful data for testing alternative mechanisms to explain masking. (Among potential complexities to be reckoned with are the many compounds that evoke substantial multiple qualities on their own.) Finally, the masking mixtures reported here are binary ones only. Many foods are more complex than that; a seasoned tomato, for example, will present sour, salty and sweet components at least.

Psycho-acoustics may serve as an encouraging model for taste mixtures. Much is known about how the auditory system integrates sounds over the audible sound spectrum

and also how different acoustical signals mask one another (for a summary see Green, 1988). There appear to be strong similarities between taste and hearing, in that both are prone to both integration and masking in mixture. Thus, just as two tastes, undetectable on their own, become detectable in mixture, so also can two inaudible tones become audible in mixture, at least within a certain fairly broad frequency range (Gässler, 1954; Spiegel, 1978). The same two tastes and same two tones can, however, also mask each other in whole or in part (Fletcher, 1953). The study of complex tastes has sometimes been presented as if a kind of after-thought about an arcane subject. It is becoming ever clearer that as in hearing mixtures rather lie at the heart of the matter.

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