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Quality-specific effects of aging on the human taste system

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Elderly persons are known to have elevated taste thresholds, with those for bitter more affected by age, for example, than those for sweet. Do analogous quality-specific effects occur at suprathreshold levels? Young (mean age = 20.3 years, *SD* = 2.99) and elderly (mean age = 72.5 years, *SD* = 4.58) subjects made magnitude estimates of sweetness, bitterness, sourness, and saltiness for the unmixed components sucrose, caffeine, citric acid, and NaCl at three concentration levels for each. They also made magnitude estimates of the separate taste qualities in two-component mixtures of sucrose with each of the other three qualities, at various levels of the two components in each mixture. Magnitude estimates of taste intensity were interweaved with magnitude estimates of the heaviness of six weights, which subjects were to judge on the same subjective intensity scale: This is the calibration feature of the method of magnitude matching, and permits the comparison of elderly and young subjects on the absolute intensity of tastes. When unmixed components were judged, elderly subjects found the characteristic tastes of caffeine and citric acid less intense than, but those of sucrose and NaCl as intense as, younger subjects did. In judging mixtures, the elderly found bitterness, but not the other three qualities, less intense than did the young subjects.

There is evidence that human chemosensitivity lessens with age (for reviews, see Murphy, 1986; Schiffman, 1986). Most psychophysical data on aging of the taste system are from threshold studies, which have demonstrated increased thresholds in the elderly. The effects of aging on taste need not be uniform across taste qualities, since different mechanisms almost certainly subserve the different qualities and more than one mechanism may encode stimuli of the same quality. Murphy (1979) reported quality-specific age effects on taste thresholds. More recent research also shows that there are larger age effects on thresholds for bitter and salty than for sweet and sour stimuli (Weiffenbach, Baum, & Burghauser, 1982).

Effects that appear at threshold may disappear at suprathreshold intensities. Is this the case with taste, or are there age-related differences in perceived intensity analogous to the liminal differences? Hyde and Feller (1981) estimated exponents for the four taste qualities, and compared the size of exponents for young and old subjects. The elderly produced smaller exponents than the young did for bitter and sour stimuli (caffeine and citric acid), but not for sweet and salty stimuli (sucrose and NaCl). Cowart (1983) obtained similar results with magnitude estimation, except that she found no age effect on the exponent for citric acid. She also reported impaired ability to discriminate sucrose and citric acid, based on an analysis of interclass correlation coefficients.

The present study extended the research reviewed above in two ways. First, young and elderly subjects were presented not only with individual components, but with mixed components, for judgments of the intensity of taste quality. Second, the method of magnitude matching (Marks & Stevens, 1980) was used to compare the absolute level of perceived taste intensity for the two age groups. Sucrose, caffeine, citric acid, and NaCl were presented alone at several concentrations for judgments of the intensity of taste quality, and mixtures of sucrose with caffeine, citric acid, or NaCl were presented for judgments of the intensity of the separate taste qualities in the mixture. On the basis of previously reported results for individual components, we expected that there would be age-related differences in the relative perceived intensities of sweetness and bitterness in mixtures, whereas there would be small (or no) differences for sweetness and sourness or saltiness.

The method of magnitude estimation can be used to compare two groups (e.g., young and elderly) on the rate at which subjective intensity of taste increases with concentration, but not to compare the two groups on the absolute level of subjective intensity: One could say that the intensity of bitterness increases at a faster rate for younger subjects, but not that any given concentration tastes more bitter to them. Magnitude matching provides a means to compare absolute levels: In the same session, subjects make magnitude estimates of stimuli on a continuum in which the presence of differences is under investigation and on a "calibration" continuum in which no differences are thought to exist. Loudness has often

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been used as the calibration continuum, but we were concerned about using loudness with elderly subjects, since hearing loss is common in the elderly and is greater for men than for women (Corso, 1981). Imposing a criterion auditory threshold may introduce bias into subject selection. Since the underlying mechanisms for sensory impairment with age are only partially understood, we do not yet know the extent to which sensory loss in one modality is related to sensory loss in another modality. Systematically eliminating elderly subjects with deficits in the auditory system may eliminate subjects at greater risk for chemosensory loss. Certainly fewer males than females would meet the criterion.

Thus, we explored weights as an alternative to sound pressure for the calibration continuum. Ten young and 12 elderly females used in the main study were also tested in a magnitude estimation pilot study, using both auditory and kinesthetic stimuli. All the participants were healthy subjects, prescreened for normal auditory threshold. By using what are generally referred to as normalization factors, one can essentially place all of the subjects' ratings on the same scale and avoid the problems posed by the individuals' tendencies to use large or small numbers. A normalization factor is a ratio of the group's geometric mean to an individual subject's geometric mean for his/her intensity ratings of the calibration continuum. A large normalization factor results when a subject tends to estimate with small numbers; a small normalization factor results from estimation with large numbers. When a subject's magnitude estimates on the continuum under investigation are multiplied by his/her normalizing factor, the proclivity of individuals to use large or small numbers is discounted. Two normalization factors were initially determined for each individual, one based on her estimates for sound and one for weight. Normalization factors were then averaged separately for sound and weight. The mean normalization factors were virtually identical (M = 1.54) and weight (M = 1.58). Hence, normalizing the estimates of taste intensity by either calibration continuum would produce the same result. For our main experiment, we selected the kinesthetic continuum, which may provide a better calibration continuum than the auditory continuum in chemosensory aging studies, since elderly subjects may not always have normal auditory function.

METHOD

Subjects

Three groups of 48 subjects each participated in one of three conditions. Each group of 48 comprised 12 men and 12 women in each of two age groups. Young subjects were 18-31 years of age (M = 20.3, SD = 3.0), and elderly subjects were 65-83 years of age (M = 72.5, SD =4.6). Sixty subjects participated in only one condition, 12 subjects participated in two conditions (6 young males and 6 elderly females), and 20 participated in all three conditions (12 elderly males, 1 elderly female, 6 young males, and 1 young female). Cognitive testing indicated that the elderly participants were intellectually capable: Mean on Raven's Progressive Matrices and the Digit Span subtest of the Wechsler Adult Intelligence Scale for the elderly were 42.7 (95th percentile for age group) and 15.2, respectively, and for the young were 52.1 (84th percentile for age group) and 17.8, respectively. Raven's scores correlate well with comprehensive intelligence test scores and are reported to be highly correlated with measures of Spearman's g. Digit Span is a test of short-term memory (Wechsler, 1955). Reasonable intelligence and good short-term memory are important in magnitude estimation tasks.

Three elderly and 6 young subjects were eliminated from the study because they were unable to perform the task. Elderly subjects were recruited from an existing pool of subjects. All were community-dwelling persons who traveled to the laboratory for participation. All reported excellent health, and none had been hospitalized within the previous year. Most of the young subjects were university students who received class credit, whereas the remaining young and the elderly subjects were paid $5 per hour for participation.

Stimuli

Stimuli for the three conditions were produced by combining the solutes rather than by mixing solutions. For the first condition, the 16 stimuli were aqueous solutions of sucrose (.15, .30, and .60 M) and caffeine (.0025, .005, and .01 M), all possible mixtures of the two solutes, and deionized water. In the second and third conditions, citric acid (.0015, .003, and .006 M) and NaCl (.10, .20, and .40 M), respectively, replaced the caffeine. Pilot work showed these concentration ranges to be of approximately equal subjective intensity for college students. All mixtures were presented at room temperature.

Brass weights of 20, 50, 100, 200, 400, and 750 g were presented in an enclosed plastic container that eliminated visual cues. For the pilot testing, 5-sec pulses of a 1000-Hz tone at 50, 60, 70, 80, and 90 dB were transmitted via calibrated headphones by a portable audiometer (Model MA27, MAICO Hearing Instruments, Inc.). Pilot work showed these values for weight and sound pressure level to be in the same subjective intensity range as the taste stimuli for young adults.

Procedure

The subjects used the method of magnitude matching (Marks & Stevens, 1980) to rate the intensity of taste and the heaviness of weights using the same number scale. The subjects were instructed to rate each stimulus in relation to the one that preceded it. The subjects practiced estimating line lengths and then sample tastants and weights.

The subjects made magnitude estimates for 16 solutions during a single testing condition. Stimuli were presented in random order. The subjects gave two ratings for each tastant, judging separately the sweetness and bitterness, sweetness and sourness, or sweetness and saltiness. A subject rinsed his/her mouth thoroughly with deionized water for 10 sec, expectorated into a cup, sipped approximately 10 ml of the tastant for 5 sec, expectorated into a cup, and rinsed with water again before the next presentation. Presentations of weights and tastants were intermingled. Weights were presented to the subject's dominant hand while his/her eyes were closed; the subject rated overall intensity.

RESULTS

Data Normalization

Estimates of taste intensity were normalized using the weight intensity judgments. First, the geometric mean of all magnitude estimates of weight was computed for each subject. Second, the condition grand geometric mean of all magnitude estimates of weight for all subjects in a given condition—sucrose and caffeine, sucrose and citric acid, or sucrose and NaCl—was computed. Third, the ratio of this condition grand geometric mean to each subject's weight geometric mean was computed. Fourth, the subject's magnitude estimates of taste intensity were multiplied by the ratio. This procedure was performed for each of the three conditions. Finally, a grand geometric mean was taken over the three conditions, and the ratio of this grand geometric mean to each condition's geometric mean was used to multiply each subject's normalized data so that judgments generated in the three conditions could be placed on the same scale.

Statistical Analysis

The normalized magnitude estimates of intensity for each condition were subjected to multifactor analyses of variance (ANOVAs) using age, gender, stimulus, and concentration as the independent variables. Separate analyses were performed on the following dimensions of each condition's stimulus matrix: unmixed components, diagonal mixtures, and off-diagonal mixtures. In these analyses, the stimulus × age interactions were of prime interest since it was predicted that there would be age-associated differences in intensity for some stimuli (e.g., caffeine) but not for others (e.g., sucrose). All effects of and interactions involving age that were statistically significant are described below.

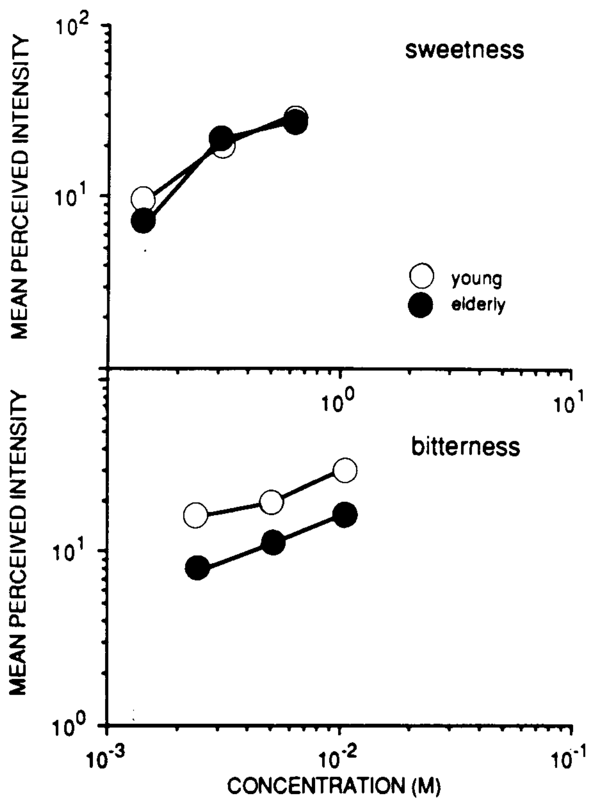

Figure 1. Mean perceived intensity as a function of concentration for the sweetness of unmixed sucrose (upper) and the bitterness of unmixed caffeine (lower). White symbols: young subjects. Black symbols: elderly subjects. The same subjects are represented in each panel.

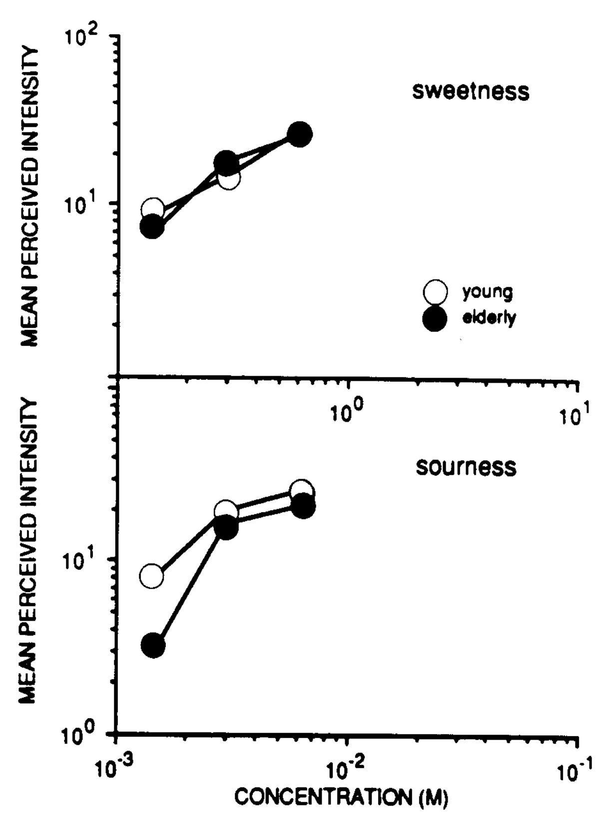

Figure 2. Mean perceived intensity as a function of concentration for the sweetness of unmixed sucrose (upper) and the sourness of unmixed citric acid (lower). White symbols: young subjects. Black symbols: elderly subjects. The same subjects are represented in each panel.

Unmixed components. The first analysis examined responses to unmixed sucrose and unmixed caffeine. Figure 1 illustrates mean perceived intensity as a function of concentration for sucrose and caffeine for both the young and elderly subjects. The ANOVA yielded significant results for the stimulus × age interaction [$F(1,44) = 10.63, p < .05, \eta^2 = .19$]. As shown in Figure 1, the two age groups did not differ in their perceptions of sucrose intensity, but, as predicted, the elderly perceived the caffeine as being less bitter ($M = 11.94$) than did the young subjects ($M = 21.5$). The effects of age were consistent over all concentration levels.

The second ANOVA examined responses to unmixed sucrose and unmixed citric acid. Figure 2 shows mean perceived intensity as a function of concentration for sucrose and citric acid for both age groups. The stimulus × age interaction was statistically significant [$F(1,44) = 4.73, p < .05, \eta^2 = .10$]. As seen in Figure 2, the two age groups did not differ in their perceptions of sucrose, but overall the elderly perceived the citric acid as being less sour (M = 13.72) than did the young subjects (M = 17.92). The effects of age were consistent over concentration.

The third ANOVA examined responses to unmixed sucrose and unmixed NaCl. As Figure 3 illustrates, the two age groups' intensity judgments did not differ significantly for either stimulus [$F(1,44) = 1.26, p \leq .27$].

Diagonal Mixtures. The second series of analyses compared the elderly and young subjects' intensity estimates of mixtures located on the diagonal of each stimulus matrix, that is, where both components were of the same concentration level (low, medium, or high). Figures 4, 5, and 6 illustrate mean perceived intensity as a function of concentration for both age groups, for sweet and bitter, sweet and sour, and sweet and salty mixtures, respectively. Figures 4–6 make it clear that for all mixture combinations and both age groups, sweetness dominated the mixtures.

Separate ANOVAs were performed to examine the effects of age on the perceived intensity of the individual tastants. The two age groups differed significantly in their responses only for bitter. As shown in Figure 4, the elderly subjects perceived the bitterness in sweet-bitter mixtures as significantly less intense than did the young subjects [$F(1,44) = 7.24, p < .01, \eta^2 = .14$].

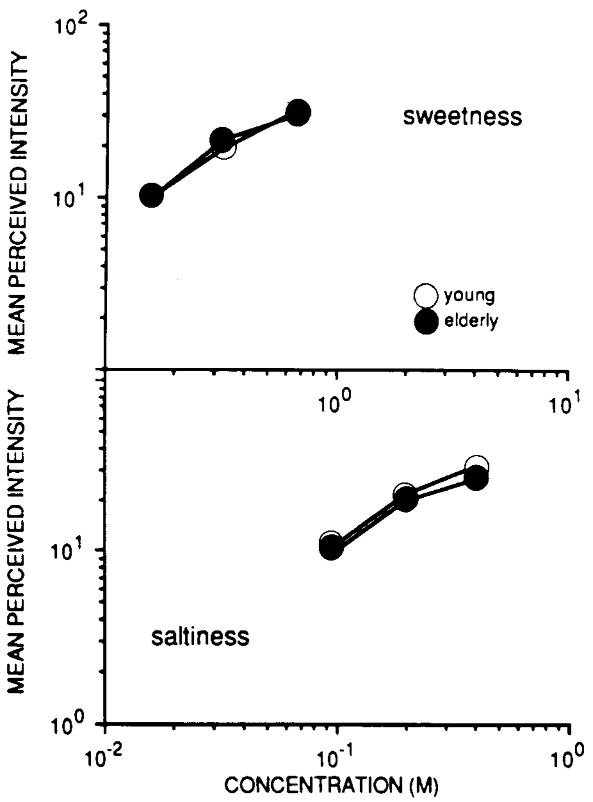

Figure 3. Mean perceived intensity as a function of concentration for the sweetness of unmixed sucrose (upper) and the saltiness of unmixed NaCl (lower). White symbols: young subjects. Black symbols: elderly subjects. The same subjects are represented in each panel.

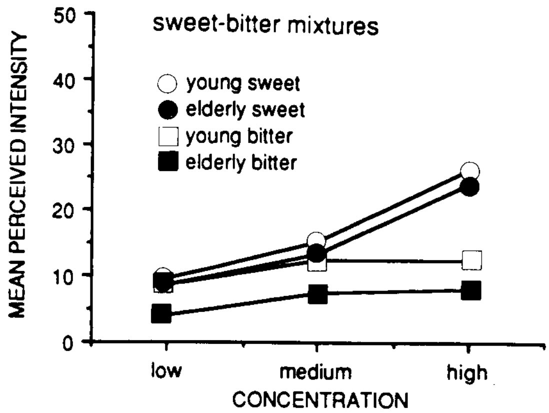

Figure 4. Mean sweetness and bitterness of isointensity mixtures when low, medium, and high concentrations of sucrose and caffeine were combined. White symbols: young subjects. Black symbols: elderly subjects. The same subjects are represented in each panel.

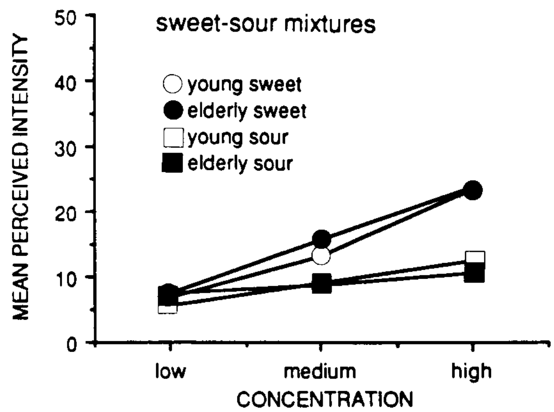

Figure 5. The mean perceived sweetness and sourness of isointensity mixtures when low, medium, and high concentrations of sucrose and citric acid were combined. White symbols: young subjects. Black symbols: elderly subjects. The same subjects are represented in each panel.

Off-diagonal mixtures. The third series of analyses compared the elderly and young subjects' perceptions of sweet and bitter, sweet and sour, and sweet and salty in mixtures of unequal concentrations, in which one stimulus would be expected to be dominant because of its concentration level. Figure 7 shows mean perceived intensity for stimuli when sweet would be expected to be dominant, and in all cases it was, with no significant age effects. Figure 8 shows the elderly and young subjects' mean intensity ratings for each stimulus when it is presented in mixtures where bitter, sour, and salty would be expected to be dominant. Figure 8 illustrates the significant stimulus × age interaction in which perceived intensity of the bitterness of caffeine is greater overall for the young than for the elderly [$F(1,44) = 5.33, p < .05, \eta^2 = .11$]. Bitter dominated these mixtures for young, but not for elderly, subjects. A Newman-Keuls analysis confirmed a significant difference between the elderly and

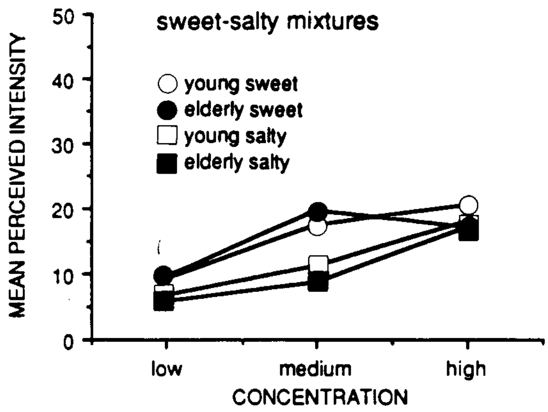

Figure 6. The mean perceived sweetness and saltiness of isointensity mixtures when low, medium, and high concentrations of sucrose and NaCl were combined. White symbols: young subjects. Black symbols: elderly subjects. The same subjects are represented in each panel.

the young subjects' perceptions of bitter, and the young subjects' perceptions of bitter and sweet ($p < .05$). The elderly subjects' perceptions of bitter and sweet did not differ significantly.

For mixtures in which salty was expected to be dominant, the higher order interaction (not shown in the figure) of stimulus × concentration × age was significant [$F(2,88) = 6.20, p < .05, \eta^2 = .12$]. The Newman-Keuls analysis indicated that perceived saltiness of these mixtures was significantly greater than perceived sweetness, with two exceptions: the strongest mixture did not differ in sweetness and saltiness for young subjects, and there was a trend for the weakest mixture to be rated as more sweet than salty by elderly subjects. This latter point is interesting since low concentrations of NaCl can taste sweet (Bartoshuk, Murphy, & Cleveland, 1978). This "sweetness" from the NaCl would add to the sweetness of sucrose and render the mixture more sweet than salty.

Gender. A subject's gender had very little effect on judgments of perceived intensity. For the sucrose and citric acid mixtures in which sour would be expected to be dominant over sweet, the stimulus × age × gender interaction was significant [$F(1,44) = 5.09, p < .05, \eta^2 = .10$]. A significant concentration × stimulus × age × gender interaction was also found [$F(2,88) = 3.12, p < .05, \eta^2 = .07$]. A Newman-Keuls analysis ($p < .05$) indicated that this interaction was due to the differences in sour judgments for elderly males and females for mixtures containing a high concentration of citric acid and a medium concentration of sucrose. Young male and female subjects also had significantly different means for the sweet judgments of the same mixture ($p < .05$). The interaction suggests that when sucrose was added to the high concentration of citric acid, the elderly males perceived the mixture as being stronger but not sweeter, and when citric acid was added to the low concentration of sucrose, the elderly males perceived the mixture as being stronger but not more sour. Adding either of the components to the mixture had very little effect for the elderly females.

For sucrose and NaCl mixtures in which salty would be expected to be dominant, the concentration × age × gender interaction was significant [$F(2,88) = 3.28, p < .05, \eta^2 = .07$]. Young females rated the weakest mixture as more intense than did young males or either group of elderly subjects. Elderly females rated the strongest of these mixtures as less intense than other subjects did.

DISCUSSION

The results of this study support the hypothesis that the effects of aging on the taste system show quality specificity that is reflected in suprathreshold function. First, elderly subjects found caffeine less bitter and citric acid less sour than did younger subjects when the substances were presented unmixed. The η^2 values for these effects

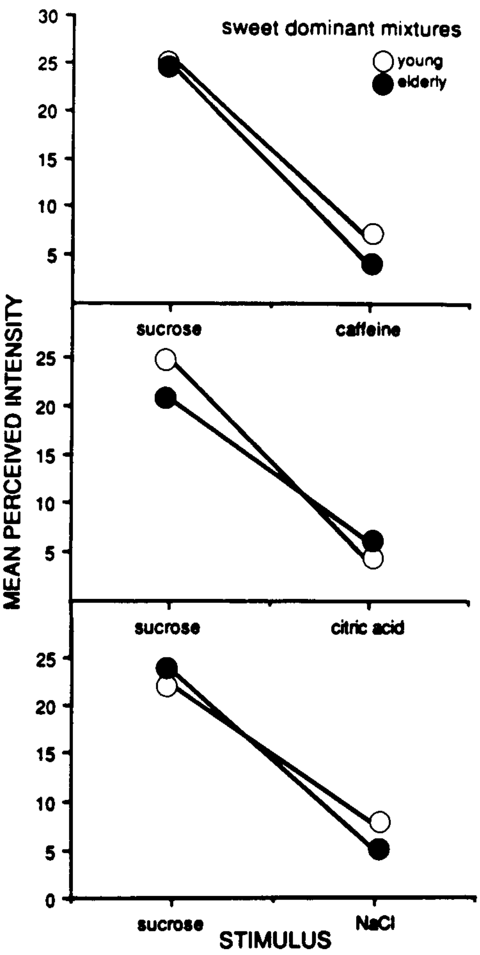

Figure 7. Mean perceived intensity of the sweetness of sucrose compared with the bitterness of caffeine (upper graph), sourness of citric acid (middle), and saltiness of NaCl (lower) when sweetness would be expected to be dominant. White symbols: young subjects. Black symbols: elderly subjects.

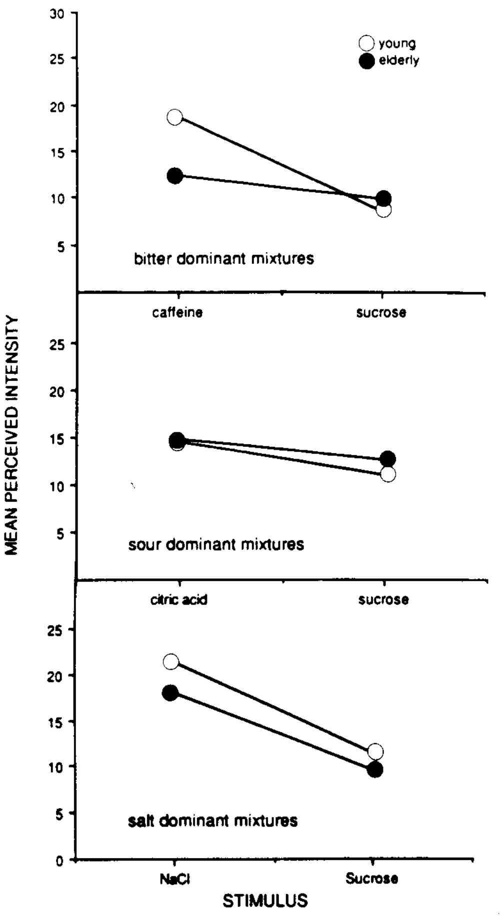

Figure 8. Upper graph: mean perceived intensity of the bitterness of caffeine and sweetness of sucrose when bitterness would be expected to be dominant. Middle graph: mean perceived intensity of the sourness of citric acid and the sweetness of sucrose when sourness would be expected to be dominant. Lower graph: mean perceived intensity of the saltiness of NaCl and the sweetness of sucrose when saltiness would be expected to be dominant. White symbols: young subjects. Black symbols: elderly subjects.

indicated that the variance in perceived intensity accounted for by age was 20% for bitterness of caffeine and 10% for sourness of citric acid. It would, of course, be interesting to investigate whether these effects are also stimulus specific within the bitter taste quality, since more than one mechanism may encode the bitter taste quality (Murphy, 1979). Sucrose tasted equally sweet to participants in the two age groups. Second, for isointensity mixtures, elderly subjects found the bitterness in sweet-bitter mixtures less intense than did younger subjects, whereas the saltiness of sweet-salty mixtures and the sourness of sweet-sour mixtures remained relatively stable over the life span. Third, for mixtures in which, on the basis of concentration, the nonsweet stimuli should dominate, bitter was dominant for the young, but not for the elderly. The dominance of salty, sour, and sweet in concentrations did not differ with age (see Bartoshuk & Cleveland, 1977).

These results are consistent with the findings of Cowart (1983) and Hyde and Feller (1981). Despite first appearances, they are not inconsistent with the recent papers by Bartoshuk, Rifkin, Marks, and Bars (1986) and Weiffenbach, Cowart, and Baum (1986). Although Bartoshuk et al. reported life-span stability in suprathreshold taste function, they did in fact find an age-associated reduction in the slope for bitterness. (They attributed the reduction to the addition of dysgeusic tastes near threshold which would have flattened the overall function, a plausible but untested hypothesis.) Weiffenbach et al. found no statistically significant age effects on slopes for psychophysical functions; however, average slope decreased with age, with the most pronounced effect for quinine sulfate. Their measure of the discriminability of suprathreshold stimuli, intraclass correlation, showed significantly poorer performance by the elderly, particularly for bitter stimuli. In both studies quinine (hydrochloride and sulfate, respectively) was used, whereas caffeine was used in the present study. Since it is likely that more than one mechanism codes the bitter taste quality, this finding may be of interest in elucidating the underlying mechanism for age effects on bitter perception.

McBride and Mistretta's (1986) recent results are particularly interesting in light of the present findings. They demonstrated age effects on neurophysiological taste responses from the chorda tympani nerve in Fischer rats. Relative to responses to NaCl, which was used as a reference, responses for NH_4Cl and sucrose increased significantly with age and responses for citric acid and $MgCl_2$, a salty-bitter stimulus, decreased. In contrast, response ratios for LiCl, KCl, and quinine hydrochloride, relative to those for NaCl, showed no effect of age. The age effect on citric acid found by McBride and Mistretta was apparently attributable to elderly males. Since it is not known whether rats' responses to NaCl change with age, it is not possible to determine whether responses for NH_4Cl and sucrose show an absolute increase, remain stable, or show an actual decrease. McBride and Mistretta predicted that response frequencies to NaCl would decrease as a function of age. If NaCl responses do decrease in old rats, then McBride and Mistretta's findings for NH_4Cl and sucrose would reflect stability over the life span for these stimuli and decreased responses for other stimuli. Thus, similar patterns of quality-specific age effects on taste emerge from very different data bases.

The present study, as well as the literature just cited, suggests a peripheral site for the etiology of the quality specificity in that age effect. Research on human taste papillae suggests that they are only widely tuned for taste quality and that the mechanism for specificity, if it exists, must be at the lower level of the taste bud or the taste cell (Cardello, 1981). The few studies available give conflicting reports regarding numbers of taste buds or taste papillae in aged humans (see Schiffman, 1986, for a review); to date, there has been no study of the functional status of taste cells in aged humans. To our knowledge, no one has recorded information about the quality specificity of single taste buds or taste cells in humans. In other species, taste fibers show widely tuned specificity in the taste system. Although the possibility of central effects cannot and should not be ruled out, differential age effects on human taste qualities would shift attention away from counting cells or buds or papillae and toward investigation of membrane and receptor function in aging cells.

The taste quality that is most affected by the aging process is bitterness. In psychophysical studies, responses to bitter stimuli take longer to build up to peak taste magnitude, persist longer, and also produce psychophysical functions with smaller slopes than do responses to other taste qualities. On a physiological level, the transduction process in the gustatory system differs as a function of the type of taste stimulus (Teeter & Brand, 1987). Suggestions that transduction for bitter stimuli may be dependent on different processes from the stimulus-macromolecular interaction processes believed to mediate responses to sugars and the ionic processes involved in mediating responses to salts raise the interesting possibility that quality-specific effects of aging may be present at the level of transduction and reflected in the psychophysical response. The inability of the aging taste system to reflect accurately the concentration of bitter stimuli may result from a saturation effect at this most peripheral level.

Differential age effects on bitterness perception may have significant implications for food ingestion. Although few foods have a predominant bitter taste, bitters serve ubiquitously as a flavor base, particularly in the beverage industry. *Fenaroli's Handbook of Flavor Ingredients* (Fenaroli, 1971) lists no fewer than 72 herbs and derivatives used to formulate bitters. Caffeine and quinine, usually in the sulfate or hydrochloride forms, add a bitterness that enhances the overall flavor of beverages. An age-related loss of a bitter component in such real-world mixtures would destroy the overall quality balance. Hence, elderly people who experience decreases in the intensity of suprathreshold bitter stimuli and increases in the threshold for bitter stimuli will have different overall taste experiences than young persons with normal bitter perception. The effects of such age-associated changes in bitter perception on taste preference need to be explored.

We suggest the use of the kinesthetic continuum in chemosensory aging studies relying on magnitude matching. Age-related losses in kinesthetic function, unlike losses in auditory function, appear to be minor. Landahl and Birren (1959) reported that subjects aged 18 to 32 years were only slightly more accurate in judging the heavier of two weights than subjects aged 58 to 85 years. Old and young subjects were equally accurate with small differences in weight. Older subjects were slightly less accurate when rapid judgments were required. Cowart (1983) reported virtually identical slopes for young and elderly subjects' magnitude estimates for heaviness of weights, which indicates that young and elderly subjects reported similar increases in perceived intensity as concentration was increased. Given the age-associated losses for perceived loudness, its use as the calibration continuum preferred in magnitude matching studies in the elderly needs to be reassessed.

Marks et al. (1988) recently assessed the degree of contextual bias in magnitude matching studies in which performance of the elderly and the young is compared. They concluded that in such studies contextual bias underestimates the effects of age and the degree of bias is dependent on the difference in perceptual levels for elderly and young for the stimuli of interest. Therefore, we expect that the results of the present study represent a conservative estimate of the effects of aging on suprathreshold taste perception.

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