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Taste Perception with Age: Generic or Specific Losses in Threshold Sensitivity to the Five Basic Tastes?

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Abstract

Detection thresholds for NaCl, KCl, sucrose, aspartame, acetic acid, citric acid, caffeine, quinine HCl, monosodium glutamate (MSG) and inosine 5′-monophosphate (IMP) were assessed in 21 young (19–33 years) and 21 elderly (60–75 years) persons by taking the average of six ascending two-alternative forced choice tests. A significant overall effect was found for age, but not for gender. However, an interaction effect of age and gender was found. The older men were less sensitive than the young men and women for acetic acid, sucrose, citric acid, sodium and potassium chloride and IMP. To detect the compound dissolved in water they needed a 1.32 (aspartame) to 5.70 times (IMP) higher concentration than the younger subjects. A significant decline in thresholds with replication was shown. The age effect found could be attributed predominantly to a generic taste loss.

Introduction

The influence of ageing on taste perception has been investigated in a large number of studies. Most of these studies were restricted in either the number of perceptual aspects (thresholds, supra-threshold intensities or preference) or in the number of basic compounds considered. As a result it is difficult to estimate the relative importance and the structural interrelationships of the differences found. The experiment to be reported here was aimed at answering two questions: whether taste losses with ageing can be found and, if so, whether these taste losses are general, basic-taste specific or compound-specific. Furthermore, the influence of gender was investigated.

For the sake of brevity, throughout the paper the term 'basic tastes' will be used for the taste qualities salty, sweet, sour, bitter and umami, without taking a position in the controversy with regard to the acceptance of umami as a basic taste.

Overviews of the results of studies concerning the effects of age on threshold sensitivity have been given by Murphy (Murphy, 1979, 1986) and by Rolls and Drewnowski (Rolls and Drewnowski, 1996), with several studies added since. An updated overview is given in Table 1.

The majority of these studies show decreases in sensitivity with age. The threshold studies directly relevant for comparison with the results to be presented here are described in more detail in Table 2. Wherever available, the age range, number of subjects, compounds and methods are given.

The studies mentioned in Table 2 differ on a number of important aspects, such as number and variety of tastants, age groups involved, health and gender of subjects, methods, and number of replications. In the following these aspects will be briefly discussed to explain the choices made in the present study.

All authors cited in Table 2 used one or more of the same taste compounds as in the present study. Some used compounds for four taste qualities, but none used several compounds for each taste quality in a single experiment to study the compound specificity and basic-taste specificity of taste losses in the same subjects with no illnesses and not taking medication. In this respect the present study is more complete, even though, in contrast to several of the studies mentioned above, only two age groups were used. For the young, the chosen age group of 19–33 years is in line with the other studies. For the elderly, the age group of 60–75 years was chosen because it is generally assumed that at 60 years a decline in sensitivity occurs, and that at 75 years the probability of major cognitive impairment is still relatively low (Schaie, 1996; La Rue, 1992). Cooper *et al.* (Cooper *et al.*, 1959) found, for instance, that taste sensitivity remains unimpaired until the late fifties, after which it shows a sharp decline. This finding might be

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Table 1 Threshold studies of basic taste compounds in aqueous solutions

Threshold studies	Year	NaCl	Sucrose sacch.	Aspart. sweeteners	HCl/citr./ acetic	Caffeine/ quinine	Glutamate	Amino acids	ptc/prop[a]	Age range
Richter, Campbell	1940		↓							7–85
Harris, Kalmus	1949								↓	10–91
Bouliere *et al.*	1958	↓	↓							n.a.
Cohen, Gitman	1959	O	O		O	O				18–94
Cooper *et al*.	1959	↓	↓		↓	↓				15–89
Kalmus, Trotter	1962								↓	n.a.
Glanville *et al*.	1964				↓	↓			↓	3–55
Kaplan *et al.*	1965					O			O	16–55
Hermel *et al.*	1970	O	↓		↓	↓				4–60
Fikentscher *et al.*	1977	↓	↓		↓	↓				0–70
Murphy	1979	↓	-		↓	↓				5–83
Grzegorczyk *et al.*	1979	↓								23–92
Schiffman *et al.*	1979							↓		17–87
Hyde, Feller	1981	O	O		↓	↓				28–75
Dye, Koziatek	1981		↓							41–88
Schiffman *et al.*	1981			↓						19–81
Moore *et al.*	1982		↓							20–88
Weiffenbach *et al.*	1982	↓	O		O	O				23–88
Bartoshuk *et al.*	1986	↓	↓		↓	↓			O	20–92
Cowart	1989	↓	O		O	O				20–87
Whissell-Buechy	1990								↓	4–78
Schiffman *et al.*	1991						↓			20–90
Stevens *et al.*	1991	↓								18–89
Schiffman[b]	1993	↓		↓	↓	↓	↓	↓	↓	n.a.
Schiffman *et al.*	1994					O/↓			↓	20–90
Schiffman[b]	1994	↓		↓	↓	↓	↓	↓	↓	n.a.
Schiffman[b]	1994	↓	O		O	O				n.a.
Stevens *et al.*	1995		↓							19–87

↓, significant decrease in sensitivity; O, no change in sensitivity.

[a]ptc, Phenylthiocarbamide; prop, 6-*n*-propylthiouracil.

[b]Review article, describing several experiments.

influenced by an increase in drug consumption with age. In the USA, the mean number of medications used by community-dwelling elderly over the age of 65 years ranges from 2.9 to 3.7 medications (Schiffman *et al.*, 1997). Dutch people of 65 years and over consume 2.9 times the amount of drugs used by the average Dutch person. This ratio even rises to four times more for people over the age of 75 years (Van der Heide, 1999). Over 250 commonly used drugs have been reported clinically to affect the sense of taste. This fact has not been taken into account in most studies mentioned in Table 2. However, Hyde and Feller (Hyde and Feller, 1981) used subjects not taking any taste-affecting medication. Other authors (Murphy, 1979; Schiffman *et al.*, 1981, 1991; Cowart, 1989; Stevens *et al.*, 1991, 1995) reported that their subjects were healthy and did not indicate having any problem with their sense of taste, but the authors did not ask about medication. In elderly free of illnesses and medication, Schiffman (Schiffman, 1994), referring to unpublished data, found only a slight trend toward elevated thresholds with age. The decrease in sensitivity only reached statistical significance for NaCl. If, however, healthy as well as elderly persons who had some illness and were taking medication were included (Schiffman, 1993, 1994), significant taste losses with age were found for many tastants. No other authors screened for health or drug use. In order to assure that eventual taste losses are exclusively age related and not complicated by illness or medication, we decided to use only healthy subjects.

Gender differences have been reported by several authors. Cohen and Gitman (Cohen and Gitman, 1959) found that men had a higher incidence of taste errors than women when they had to recognize the basic tastes of sour, sweet, salty and bitter. Glanville *et al.* (Glanville *et al.*, 1964), using subjects from 3 to 55 years of age, found that both males and females showed a gradual increase in sensitivity up to the age of 16–20 years, followed by an exponential decline.

Table 2 Survey of threshold studies comparable to the present study

Author(s)	Year	Males	Females	Gender unspec.	No. of groups	Age	Comp'ds	Age diff.	Gender diff.	Notes	Method	Reps
Cohen and Gitman	1959	18 30 144	27 25 104		1 2 3	18–39 40–64 65–94	NaCl, sucrose, acetic acid, quinine sulphate	Overall $P < 0.07$	males made more mistakes	recognition of sour taste most frequently missed	2 of 3 responses fixed concs above threshold	1
Cooper *et al.*	1959	80	20	25 16 23 27 9	1 2 3 4 5	15–29 30–44 45–59 60–74 75–89	NaCl, sucrose, HCl, quinine sulphate	sweet, salty and bitter sharp decrease after fifties	no	subjects were blindfolded	ascending method	3
Hermel *et al.*	1970			24 26 21 21 33	1 2 3 4 5	4–6 7–11 12–14 20–25 48–60	NaCl, sucrose, citric acid, quinine sulphate	sweet, sour and bitter	n.a.	removal of dentures improved taste perception	step up	1
Fikentscher *et al.*	1977	20 20 20 20 20 20 20	20 20 20 20 20 20 20		1 2 3 4 5 6 7	0–10 10–20 20-30 30–40 40–50 50–60 60–70	cane sugar, citric acid, NaCl, quinine	sweet, sour, salty and bitter	females more sensitive all tastes significant after age 40		moistened probe	1
Murphy	1979	7 7 7 7 7 7 7	7 7 7 7 7 7 7		1 2 3 4 5 6 7	5.5–6.5 11.3–12.5 17.8–19.5 22.0–23.8 28.5–35.0 48.1–58.0 65.7–83.6	NaCl, sucrose, citric acid, tartaric acid, HCl, caffeine, quinine sulphate and magnesium sulphate	overall effect of age, age × tastant, age × sex × tastant	no sex- and no sex interaction effects		ascending method of limits	1
Hyde and Feller	1981	12 12	12 12		young elderly	28.1± 3.4 75.0± 6.0	NaCl, sucrose, citric acid, caffeine	caffeine, citric acid	no overall gender diff.	males less sensitive to NaCl	comb. forced choice discrim. and intensity scaling methods	3
Schiffman *et al.*	1981		12 12		young elderly	19–24 75–81	11 sweeteners	aspartame, monellin a.o.		PTC tasters	noseplugs, f-choice triangle 3-on-a-row geometric mean	1
Weiffenbach *et al.*	1982	16 10 16	15 14 10		1 2 3	<45 46–65 ≥66	NaCl, sucrose, citric acid, quinine sulphate	NaCl	males less sensitive to citric acid		2AFC, up-down round robin fashion	1

Table 2 Continued

Author(s)	Year	Males	Females	Gender unspec.	No. of groups	Age	Comp'ds	Age diff.	Gender diff.	Notes	Method	Reps
Bartoshuk *et al.*	1986	2	16		young	20–30	NaCl, sucrose, citric acid, quinine HCl, PROP	NaCl, sucrose, citric acid, quinine		no decrease in PROP-sens. dentures in	up-down 4AFC	1
		2	16		elderly	74–93						
Cowart	1989	56	81		≥19 ≥19 ≥19 ≥19 ≥19 ≥19	20–30 30–40 40–50 50–60 60–70 >70	NaCl, sucrose, citric acid, quinine sulphate	NaCl, quinine		males less sensitive to NaCl and citric acid	FC staircase round robin fashion	1
Schiffman *et al.*	1991	6 1	10 17		young elderly			MSG, IMP a.o.	MSG, IMP a.o.	n.a.	forced choice triangle 3-on-a-row geometric mean	1
Stevens *et al.*	1991	6 7 5	15 13 15		young middle elderly	18–30 35–56 67–89	NaCl	elderly less sensitive than young	n.a.		transformed up–down; one incorrect—up; two correct—down	1
Schiffman *et al.*	1994			16 18	young elderly	27.4 ± 1.2 81.3 ± 1.7	quinine HCl, caffeine, a.o. bitter compounds	quinine HCl a.o. not for caffeine	n.a.	subjects wore nose-plugs	FC triangle, asc 3-on-a row	2
Schiffman	1994			140	7(20)	n.a.	NaCl, citric acid, sucrose, quinine HCl a.o.	NaCl	n.a.	white and black no race effect	n.a.	n.a.
Stevens *et al.*	1995			15 15	young elderly	<27 >64	sucrose	elderly less sensitive than young	n.a.		transformed up–down; one incorrect—up; two correct—down	6

Sensitivities to 6-*n*-propylthiouracil (PROP) and quinine were similar in the two sexes up to the age of 16–20 years, but from this age onward men declined at a faster rate than women. For HCl, females were more sensitive tasters from early childhood until adolescence, where almost equal maximum sensitivity for both women and men was reached. After this, sensitivity to HCl also decreased more rapidly for men than for women. Weiffenbach *et al.* (Weiffenbach *et al.*, 1982) found that within each age group the thresholds of men were higher than those of women. Other authors did not find gender differences, whereas some authors did not look for this (see Table 2).

The methods vary widely among the previous studies in: procedures to determine thresholds; concentration ranges; amount of solution to be tasted; instructions; and experience of subjects with the experimental procedure. While some authors used a two-alternative forced choice (2AFC) method (Weiffenbach *et al.*, 1982; Cowart, 1989; Stevens *et al.*, 1991), others used a 4AFC method (Bartoshuk *et al.*, 1986), a triangle method (Schiffman *et al.*, 1981) or a one-alternative recognition task (Cohen and Gitman, 1959). Some authors used only four fixed concentrations (Hermel *et al.*, 1970; Fikentscher *et al.*, 1977), while others used a range not broad enough to fit all subjects in (Grzegorszyk *et al.*, 1979). While in most studies ~10 ml solution was presented to be swirled around in the mouth so as to contact all taste buds and then to be expectorated, Cohen and Gitman (Cohen and Gitman, 1959) and Fikentscher *et al.* (Fikentscher *et al.*, 1977) used moistened probes to wipe across different areas of the tongue. Hermel *et al.* (Hermel *et al.*, 1970) used 0.1 ml drops of solution and Grzegorczyk *et al.* (Grzegorczyk *et al.*, 1979) stressed the importance of instructing subjects to rinse the mouth between stimuli. Many elderly people have increased salivary sodium concentrations (Grad, 1954) and may demonstrate higher thresholds due to salivary composition rather than a deficiency in the sensory apparatus. An effect of practice with repeated measurements has been found in several studies of olfactory stimuli (Engen, 1960; Cain and Gent, 1991).

These factors might well have influenced the absolute thresholds found per age group. The method of repeated threshold measures used in the present study has been recommended by Stevens and Dadarwala (Stevens and Dadarwala, 1993) and Stevens *et al.* (Stevens *et al.*, 1995), who showed that the variability in thresholds for age groups narrows markedly as the number of tests averaged increases from one up to four or six. They have also argued that a more reliable picture of a subject's sensitivity can be obtained from several short sets of trials separated by brief rest intervals than from an equal number of trials unbroken by rests. In the present study these recommendations are followed by using six sessions. This has the added advantage that for taste stimuli a learning effect of practice, similar to that described by Engen (Engen, 1960), Rabin and Cain (Rabin and Cain, 1986), and Cain and Gent (Cain and Gent, 1991) for olfactory stimuli, can be investigated in different age groups.

Materials and methods

Subjects

Twenty-one older subjects (age 60–75 years: 10 male, mean = 66.0, SD = 3.6; 11 female, mean = 64.6, SD = 4.2) and 22 young subjects (age 19–33 years: 11 male, mean = 26.5, SD = 3.6: 11 female, mean = 23.2, SD = 3.3) participated in the experiment. All subjects were Caucasian and met the following criteria: healthy, not on a diet; not living in a home for the elderly; not taking any prescribed medicine; non-smoking; not heavy alcohol users; non-pregnant or lactating; not subject to food allergies; good dental hygiene; not wearing dentures (as it was very difficult to recruit enough elderly persons without dentures, subjects with partial dentures were admitted, but they were not allowed to wear these during testing); and within the normal range at hearing sounds of 750 Hz in view of the use of hearing as a matching modality for taste in later experiments. Furthermore, a rough estimation of the individual threshold for all substances used in the experiment was obtained by a paired comparison test in which seven concentrations (a range based on the literature, with a 0.4 log step increase) of the tastants in water were compared with blanks in an ascending staircase procedure. The subjects had to identify the solution containing the tastant and to indicate how certain they were of their choice. This pre-test enabled us to use individually tailored ranges of stimuli in the main threshold experiment, which were embedded in the total range of stimuli. Subjects were selected on a volunteer basis in response to advertisements in local newspapers and on bulletin boards in senior citizen centres. At the end of the full experiment the subjects were paid a fee for participation.

Stimuli

Stimuli representing the four classical basic tastes—saltiness, sweetness, sourness, and bitterness—as well as umami were included. For each taste two representative compounds were chosen. For each compound 14 concentrations were prepared in successive 0.2 log dilutions with distilled water. The total range of concentrations was chosen on the basis of threshold values reported in the literature (Schiffman *et al.*, 1981; Weiffenbach *et al.*, 1982; Bartoshuk *et al.*, 1986; Cowart, 1989; Stevens *et al.*, 1991; Schiffman, 1993) and were adjusted after the first measurements. [After the two threshold measurements on the first day of the experiment all ranges were adjusted, since some individuals occasionally detected the lowest concentration of different compounds (especially of citric acid and quinine), and the highest concentration of one compound (IMP) was not detected once by one of the older subjects.] This resulted in the following ranges of tastants in water in g/l: saltiness—sodium chloride 1.11×10^{-2}–6.98 and potassium chloride 2.23×10^{-2}–8.90; sweetness—sucrose 4.09×10^{-1}–1.63×10^{2} and aspartame 0.82×10^{-3}–3.27×10^{-1}; sourness—acetic acid 0.60×10^{-3}–2.39×10^{-1} and citric acid 5.28×10^{-3}–2.10; bitterness—caffeine 7.73×10^{-3}–3.08 and quinine hydrochloride 2.49×10^{-4}–0.99×10^{-1}; umami—monosodium glutamate (MSG) 7.45×10^{-3}–2.97 and inosine-5′-mono-phosphate (IMP) 9.85×10^{-2}–3.92×10^{1}. The solutions were stored and tested at room temperature and never kept for longer than 2 days.

Procedure

The subjects took part in six testing sessions held on six different days, 3 days in a row per week. The compounds were divided in two sets of five basic tastes each. One set contained NaCl, sucrose, acetic acid, caffeine and MSG; the other set consisted of KCl, aspartame, citric acid, quinine

HCl and IMP. Per day one set was presented in a fixed order as described above, with a short break between two tastants. Thresholds for MSG and IMP were determined last because from industrial experience we have found that the affinity of MSG and IMP for taste receptors may cause spuriously high perceived intensities of some of the other compounds when they are to be tasted after the umami tastants. A second series followed after a 10 min break. Over successive days the two sets were alternated. The sessions were split for the elderly and the young for practical reasons: more time and more elaborate instructions were required for the elderly.

The procedure entailed a two-alternative forced choice, with concentrations presented in ascending order, the so-called 2AFC-5-in-a-row method used by Stevens and Cain (Stevens and Cain, 1987) and based on the method developed by Wetherill and Levitt (Wetherill and Levitt, 1965). On each trial, a participant received two 30 ml disposable plastic cups, one with 10 ml taste solution and one with 10 ml distilled water. The two cups were placed side by side in front of the subject in a left–right position randomly chosen from trial to trial. The sip-and-spit method was used. At the start of the session and before each trial the subject rinsed with distilled water and expectorated. The samples, both blanks and taste solutions, were swirled around in the mouth briefly and expectorated. After indicating which cup contained the tastant, the participant received another pair. The subjects were instructed to eat a piece of cream cracker after rating the last pair of a tastant. To prevent excessive fatigue, testing began at a concentration level two steps below the individual threshold concentration level that had been determined in the screening procedure. Whenever the subject selected incorrectly, the next trial took place at the next higher step. When the subject selected correctly, the same concentration was presented again. Testing ceased after five correct answers in a row. However, if the first five trials were correct right away, they were followed by the next lower concentration. The geometric mean of the last and the second last concentration was calculated and taken as the individual threshold.

Statistical analysis

Methods

Statistical analyses were conducted using SAS® and SAS/STAT®. Multivariate analysis of variance (MANOVA) was applied with age and gender as between-subject factors, and basic taste, compound and replication as within-subject factors, in order to investigate the main and interaction effects of age, gender, basic taste, compound and replication. The same error was used to test the effects of the mean, age, gender and age × gender per multivariate response (e.g. compound). Repeated measures analyses of variance were applied multivariately with replication and compound, and with replication, basic taste and compound within basic taste, as factors. Data were averaged over replications for pairwise comparisons of the older men, older women, young men and young women using the least squares means method. Principal component analysis (PCA) (Jollife, 1986) was conducted to determine interrelationships between taste sensitivities. Separation of variances into variance components (see Results, section on 'General or specific losses') was done using Proc Varcomp of SAS/STAT.

Levels of significance

We report all effects that have a P-value of 0.05 or lower as 'significant'. Power analysis shows that, with the number of subjects in our study, an effect with a magnitude of 1.3 standard deviations and a P-value of 0.10, still has a power of 0.90. Therefore we additionally report a selection of the more interesting effects with a P-value between 0.05 and 0.10. These effects will be denoted as 'trends' or 'tendencies'.

Results

Overall effects

A significant decline in thresholds with replication [$F(5,34) = 7.52$, $P < 0.0001$] was found, indicating an effect of practice. The MANOVA revealed a significant overall effect for age [$F(1,38) = 10.32$, $P < 0.003$], but not for gender, nor for the interaction age by gender. However, comparison of group means (LSMeans) taken over the six replications showed that the older men deviated from the other groups. In general, the older men were less sensitive than the young ($P < 0.001$) and tended to be slightly less sensitive than the older women ($P < 0.07$). Table 3 gives an overview of the mean thresholds.

Compounds

Age effects were not equal for all compounds [$F(9,30) = 3.15$, $P < 0.01$]. A more detailed analysis of the effects, specified for compounds, showed significant age effects [with all Fs (1,38)] for NaCl [$F = 8.17$, $P < 0.007$], KCl [$F = 13.70$, $P < 0.001$], citric acid [$F = 5.49$, $P < 0.03$], and IMP [$F = 23.78$, $P < 0.0001$]. Only trend effects of age were found for sucrose [$F = 2.89$, $P < 0.10$] and caffeine [$F = 3.20$, $P < 0.10$], whereas sucrose elicited a gender effect [$F(1,38) = 5.99$, $P < 0.05$] and acetic acid showed a trend effect of age [$F(1,38) = 4.04$, $P < 0.10$]. Women tended to have lower thresholds for sucrose and acetic acid than men. Besides the age effect for IMP, there was also an age by gender interaction effect [$F(1,38) = 6.01$, $P < 0.02$]. A comparison of group means taken over the six replications showed that the older men had significantly higher thresholds than the young women for six compounds: NaCl ($P = 0.01$), KCl ($P = 0.003$), sucrose ($P = 0.01$), citric acid ($P = 0.02$), caffeine ($P = 0.03$) and IMP ($P = 0.001$). In four of the ten cases they also had higher thresholds than the young men; NaCl ($P = 0.004$), KCl ($P = 0.002$), citric acid ($P = 0.03$) and IMP ($P = 0.0001$). For sucrose ($P = 0.03$), the older men had higher thresholds than the older women, whereas for NaCl (P = 0.08), acetic acid (P = 0.10) and IMP (P = 0.07) the older men seemed to show a deterioration in taste compared to the older women. The older women seemed to have higher thresholds than young women for the compounds KCl (P = 0.08) and IMP (P = 0.09) and significantly higher thresholds than the young men for IMP (P = 0.002) (Figure 1).

Since the young men and women did not differ significantly in thresholds, their average thresholds were taken for comparison with the results of the elderly men or women. The older men were less sensitive than this average of young men and women for acetic acid, sucrose, citric acid, sodium and potassium chloride and IMP. To detect the tastant dissolved in water they needed a 1.32 (aspartame) to 5.70 times (IMP) higher concentration than the young (Figure 2).

Compounds within basic tastes

When the two compounds within the basic tastes were compared, significant differences in thresholds were found, as was to be expected, since the concentration ranges were not matched for perceived intensity. An age by compound within-basic-taste interaction effect was found for the umami taste, where the difference between the elderly and the young was much larger for IMP than for MSG [$F(1,38) = 9.74$, $P < 0.005$]. Furthermore, it could be shown that within each of the basic tastes, the sensitivity for the compound with the higher mol. wt decreased most with age.

Basic tastes

Age effects were not equal for every basic taste [$F(4,35) = 5.19$, $P < 0.01$]. Pairs of basic taste compounds were used as contrasts in the MANOVA. The age effects were of similar magnitude for the salty, bitter and umami tastants on the one hand, and the sweet, sour and bitter tastants on the other hand. There was a larger difference between the elderly and the young for the salty than for the sweet basic tastants [$F(1,38) = 9.29$, $P < 0.005$] and the sour tastants [$F(1,38) = 5.44$, $P < 0.05$]. A larger age difference was also found for the umami than for the sweet [$F(1,38) = 14.52$, $P < 0.001$] and the sour tastants [$F(1,38) = 6.59$, $P < 0.05$]. No gender or age by gender interaction effect on the differences was found.

Cumulative threshold curves

Inspection of the group threshold curves for young and elderly people, averaged over replications, indicated four types of differences between these curves. The first type, observed for aspartame, acetic acid and perhaps sucrose, shows hardly any difference between the young and the elderly. The onset and the completion of the curve are located at about the same concentration and the slope is similar in steepness (Figure 3d,e,c), indicating that the young and elderly did not differ in mean thresholds and standard deviations. In the second type, observed for citric acid, sodium and potassium chloride, the onset of the curve is at the same concentration for the young and the elderly,

Table 3 Mean thresholds in 0.2 log concentration steps and in g/l and standard deviations (SD) per age *x* gender group: male elderly (ME), female elderly (FE), male young (MY) and female young (FY)

Compound	Mol. wt	Mean conc. step				Conc. (g/l)	Mean (g/l)			
		ME	FE	MY	FY		ME	FE	MY	FY
NaCl	58.44	9.40 (2.32)	8.11 (2.63)	7.14 (2.52)	7.40 (1.72)	0.01106	0.83915	0.46327	0.29636	0.33407
KCl	74.55	8.78 (2.91)	7.64 (2.74)	5.94 (2.15)	6.12 (2.45)	0.02234	1.27392	0.75360	0.34446	0.37423
Sucrose	342.30	6.50 (2.19)	5.24 (1.33)	5.53 (1.57)	4.90 (1.56)	0.40882	8.15709	4.56599	5.21838	3.90423
Aspartame	294.31	7.53 (2.57)	6.88 (1.83)	6.83 (2.22)	7.03 (1.83)	0.00082	0.02629	0.01949	0.01904	0.02088
Acetic acid	60.05	8.40 (2.95)	6.94 (2.54)	7.77 (2.52)	6.77 (2.20)	0.00060	0.02872	0.01466	0.02149	0.01356
Citric acid	210.15	5.13 (2.61)	4.24 (1.87)	3.80 (1.67)	3.63 (1.30)	0.00527	0.05605	0.03720	0.03038	0.02809
Caffeine	194.19	8.48 (3.07)	7.61 (1.80)	7.39 (2.49)	6.70 (2.22)	0.00773	0.38392	0.25718	0.23239	0.16914
Quinine HCl	396.92	6.83 (3.13)	6.23 (2.24)	5.54 (2.83)	5.27 (1.88)	0.00025	0.00581	0.00440	0.00320	0.00283
MSG	187.13	9.03 (3.27)	8.68 (2.45)	7.53 (2.81)	8.05 (2.43)	0.00745	0.47660	0.40565	0.23887	0.30349
IMP	392.17	8.03 (3.59)	6.41 (3.17)	3.58 (1.93)	4.93 (2.19)	0.09851	3.97627	1.88572	0.51224	0.95384

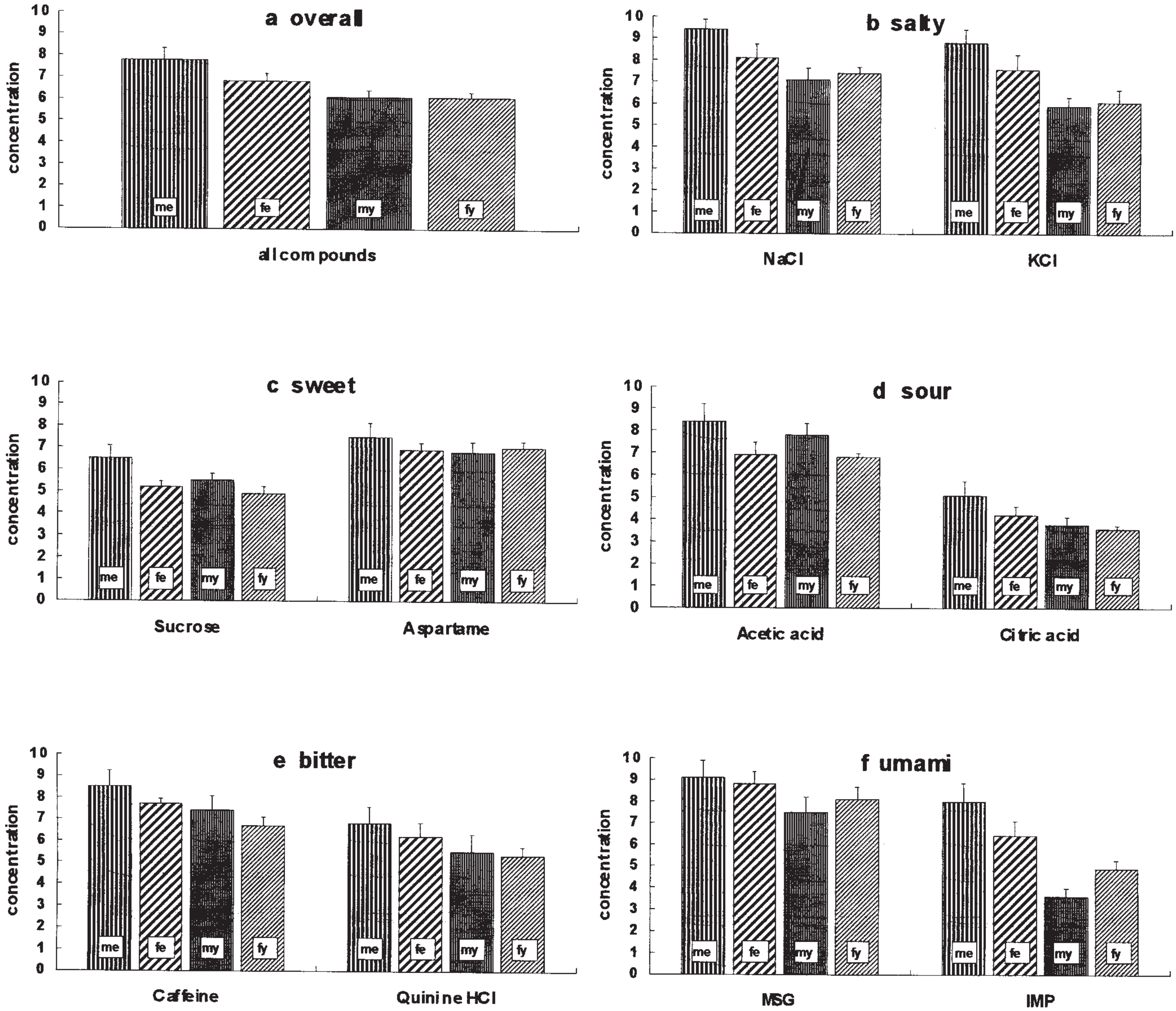

Figure 1 Thresholds of elderly male (me), elderly female (fe), young male (my) and young female (fy) subjects for ten compounds representing five basic tastes. Values are mean thresholds ± SEM and they are given in 0.2 log concentration steps.

but the curve is completed at a higher concentration in the elderly (Figure 3f,a,b). Thus, the slope of the curve is less steep for the elderly, indicating that the mean thresholds were higher and the standard deviations larger for the elderly than for the young. The third type, observed for caffeine and MSG, shows the onset and completion of the curve both at a higher concentration for the elderly than for the young, while the slope for the elderly and young is similar (Figure 3g,i). The last type of curve, obtained for quinine and IMP, also shows a later onset and completion, but in the case of the elderly the slopes are flatter, indicating that the mean thresholds for these compounds were higher and the standard deviations larger (Figure 3h,j).

In no case was the onset and/or completion at lower concentrations or the slope steeper for the elderly than for the young.

Overall learning effect

MANOVA revealed that the overall effect of replication was due to a linear learning effect [$F(1,38) = 38.69$, $P < 0.0001$]. There was no significant age or gender effect, but there was a significant interaction effect of age by gender [$F(1,38) = 5.32$, $P < 0.05$]. Taken over all compounds, the thresholds for the older men did not decrease significantly, whereas the decline in threshold curve was most pronounced for the young men and the thresholds for the women showed an intermediate decline (Figure 4a).

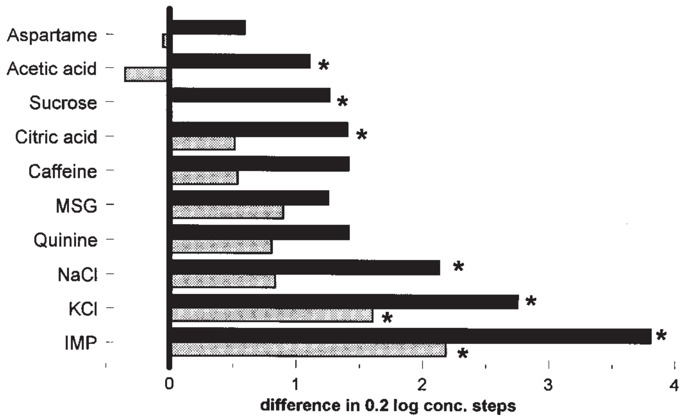

Figure 2 Differences in threshold between elderly male or female subjects and young persons for ten taste compounds. The vertical axis represents the mean threshold of the young subjects. Asterisks indicate a significant difference ($P < 0.05$) between the mean thresholds of the elderly male or elderly female and the means of the young males and females taken together. A 0.2 log step represents a multiplication of the concentration by 1.58.

Learning effect per compound

Specified for the different compounds, MANOVA showed a significant linear learning effect $F(1,38)$ for NaCl [$F = 4.80$, $P < 0.05$], sucrose [$F = 4.14$, $P < 0.05$], aspartame [$F = 6.01$, $P < 0.05$], acetic acid [$F = 18.61$, $P < 0.0001$], citric acid [$F = 41.31$, $P < 0.0001$], caffeine [$F = 8.25$, $P < 0.01$] and MSG [$F = 4.18$, $P < 0.05$], whereas a trend effect could be seen for KCl [$F = 3.33$, $P < 0.10$]. No significant age by linear learning interaction effect was found, although a trend could be noticed for NaCl [$F = 3.91$, $P < 0.10$]. For sodium chloride, the older men seemed to differ from the other subgroups. They did not learn to detect sodium chloride at a lower concentration. In general, the performance of men and women did not differ with practice, but a significant interaction effect of age by gender by replication was found for MSG [$F = 4.12$, $P < 0.05$] and a trend for KCl [$F = 3.66$, $P < 0.10$]. In both cases the thresholds of the older men increased while the thresholds of the young men decreased most strongly over sessions.

Although no quadratic learning effect was found when the thresholds for the compounds were pooled, such an effect was observed for citric acid [$F(1,38) = 10.03$, $P < 0.005$] and IMP [$F(1,38) = 9.15$, $P < 0.005$] when analysed separately. A tendency towards an age by quadratic learning interaction effect was found for NaCl [$F(1,38) = 2.84$, $P < 0.10$] and for aspartame [$F(1,38) = 3.31$, $P < 0.10$] (see Figure 4b–f).

Differences in compound learning within the basic tastes

Within the basic tastes the linear learning effect was not different for the two compounds. An age by compound (within basic taste) by replication effect was observed with the sour tastants [$F(1,38) = 4.37$, $P < 0.05$], where the elderly showed a flatter slope in the learning curve for acetic acid than for citric acid, while the slopes of the young were identical. This flatter slope was caused predominantly by the elderly men, who, over sessions, did not learn to detect acetic acid at a lower concentration as did the other sub- groups. But the elderly men did learn at the same rate as the others when citric acid was the tastant. The umami taste also showed an age by replication by compound (within basic taste) effect [$F(1,38) = 4.96$, $P < 0.05$]. The slope for the elderly was more or less flat for MSG, while the slope for IMP was flat for the young. For MSG the thresholds of the young and for IMP the thresholds of the elderly decreased over sessions. Figure 4f shows that this contrast was caused by the different behaviour of the elderly men in the case of MSG and by the young women in the case of IMP. The large difference in initial thresholds for IMP between the elderly and the young largely disappeared over replications due to the results of the women. For IMP the difference between the older and the young men remained constant, but the older women showed considerable learning, whereas the young women seemed to become less sensitive to IMP over time.

Differences in learning between basic tastes

No significant difference in overall linear learning effect was observed between the salty, sweet, bitter and umami tastes, although the learning effect for the sour taste was stronger than that for the other basic tastes ($P < 0.05$ in all cases).

General or specific losses

The total variance due to age could be separated into the following variance components: age 93%, age × basic taste 4%, age × compound (basic taste) 1% and error 2%. This shows that the age effects found can be attributed predominantly to a generic taste loss.

Relationships between the sensitivities to different tastants

Table 4 shows that the sensitivities to the tastants were more strongly interrelated for the elderly than for the young. For the elderly, almost all sensitivities to tastants were correlated, but no significant correlation was found between the sensitivity to sucrose on the one hand and to that of sour and bitter tastants on the other. Sensitivity to KCl was not correlated with that of either acid, while sensitivity to NaCl was. The sensitivities to aspartame, MSG and IMP were correlated with those to all other tastants. Remarkably, for the young no correlation was found between the sensitivity to IMP and any other tastant, and the sensitivity to NaCl was only significantly correlated with that to acetic acid.

Biplots are used in Figure 5 to demonstrate the main information in the data. The sensitivities to the tastants are represented on the map by vectors running from the centre. The relationship between the sensitivities to the tastants is expressed by the angle they form at the origin. The smaller

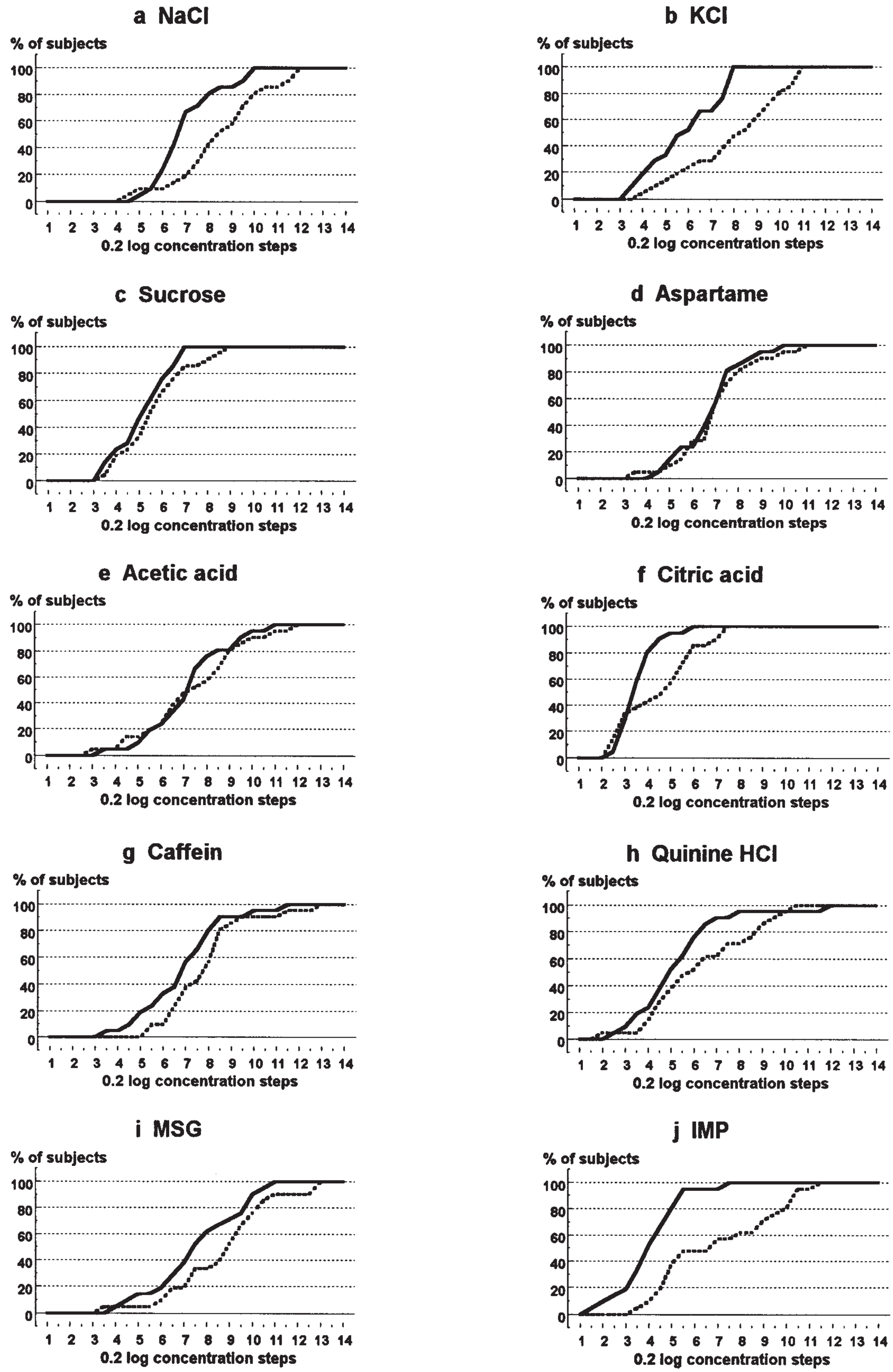

Figure 3 Cumulative threshold curves of 21 elderly and 21 young subjects for ten taste compounds. Solid lines represent the young and dotted lines represent the elderly subjects.

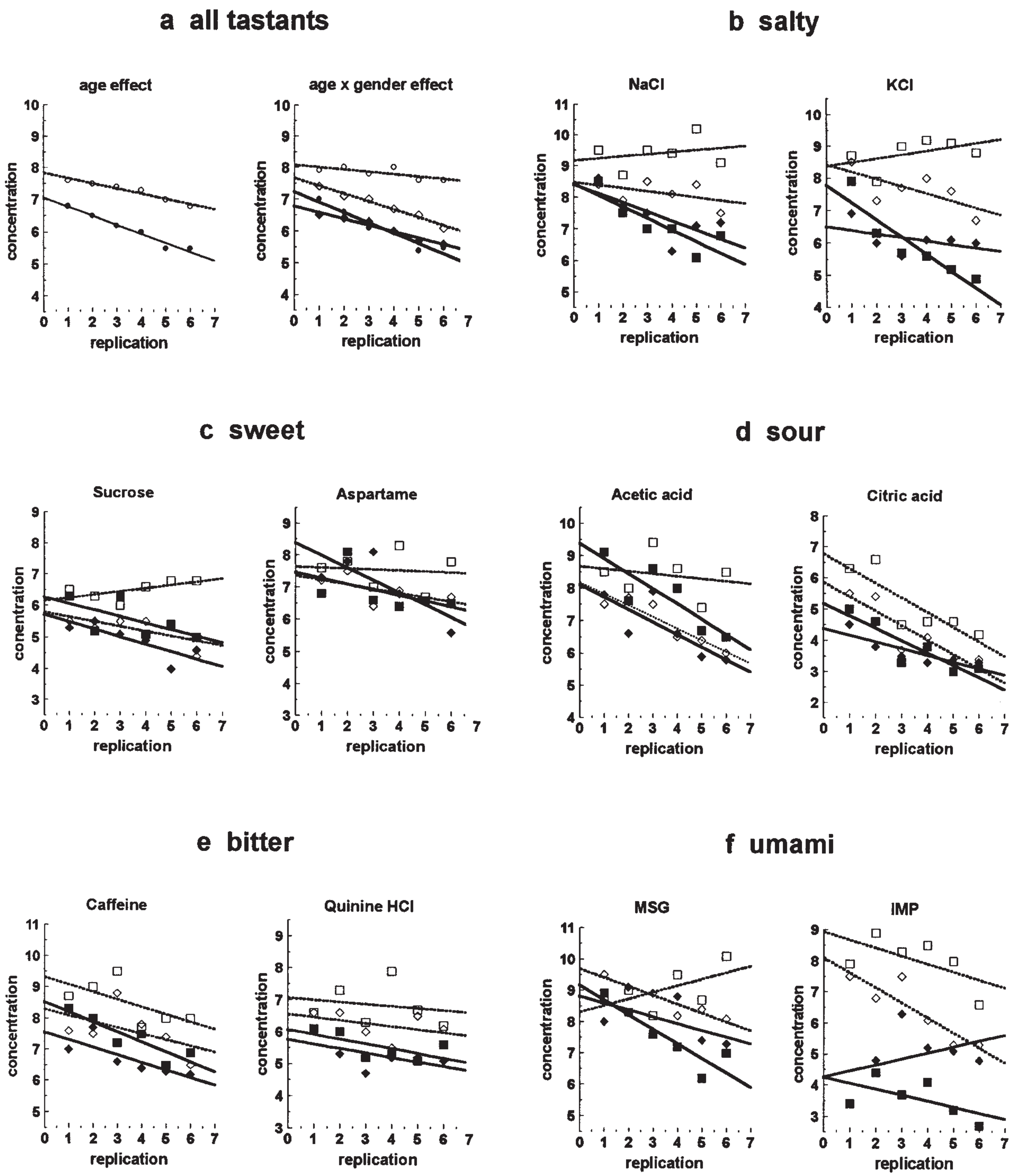

Figure 4 Repeated threshold measurements for ten taste compounds in young and elderly male and female subjects. Thresholds are given in 0.2 log concentration steps. The young subjects are represented by solid lines and filled marks, the elderly by dotted lines and open marks. The male subjects are represented by squares and the female subjects by diamonds.

the angle, the higher the correlation. Sensitivities to tastants running in opposite directions had a high negative correlation. The length of a vector is proportional to the standard deviation of the threshold scores for that particular tastant. The perpendicular projection of a subject point on a particular vector represents the threshold score of that subject for the corresponding tastant. A point on the vector far from the origin indicates a high threshold score, meaning that that person was relatively insensitive to the particular tastant; a point far from the origin in the opposite direction on the extended vector indicates a low threshold score, meaning that that person was relatively sensitive to that tastant. The dimensions in a biplot are arranged in order of amount of explained variance. Note that the primary axes have no meaning of their own, but that they derive their meaning from the major discriminating tastant sensitivities that are highly correlated with them. The coordinates for the origin are calculated by taking a mean threshold score across all subjects for each individual tastant. This means that in order to find a subject at the origin he or she would need to have the overall mean threshold scores for each of the tastants. In a sense, he or she would be a person of 'average' sensitivity.

For the elderly, only two dimensions were needed to explain 73% of the variance in the threshold data, whereas for the young four dimensions were needed to explain almost the same amount of variance and their compound vectors were more spread over and within the dimensions, meaning that specificity in taste perception was greater in the young than in the elderly. There were also differences in the groupings of the taste sensitivities between the age groups. Taste sensitivities of the elderly were clustered in two groups: sucrose–KCl–NaCl–IMP and aspartame–MSG–citric acid–acetic acid–quinine–caffeine, each with highly correlated tastants, meaning that when an older person had a high threshold for one of these tastants, he or she had high thresholds for the other tastants as well. Only 53% of the variance in the threshold scores of the young were displayed by the first two dimensions. Citric acid, acetic acid and NaCl formed one cluster, while quinine, caffeine, aspartame, sucrose and MSG formed another cluster. The third and fourth dimension, taken together, explained another 24% of the variance for the young subjects. The sensitivity to IMP lay in the third dimension, while that to KCl lay predominantly in the fourth dimension. Thus, not only is there a general loss in sensitivity with age, but this loss also expresses itself in a diminished specificity of the taste sensitivity.

Discussion

Although the results of this study confirm the findings of other authors with regard to a general decrease in taste acuity in the elderly (Cooper *et al.*, 1959; Fikentscher *et al.*, 1977; Murphy, 1979; Bartoshuk *et al.*, 1986), they contain additional information on a number of points which are still under discussion. Of the variance attributable to age and its interactions, age appeared to be accountable for 93%, basic taste qualities for 4% and compounds for 1%. Thus, it becomes clear that the decrease in sensitivity with age found here was generic in nature, even though the extent of the decrease differed for the basic taste qualities and, to a lesser degree, for the compounds within a basic taste. The salty and umami taste qualities seemed to be affected most (Figure 2). The findings in our study are not in accordance with other previous findings (Cohen and Gitman, 1959; Hermel *et al.*, 1970) on the acuity for sweet, salty, sour and bitter tasting compounds. Cohen *et al.* reported no significant general decrement in taste recognition, but their data seem to indicate a significant loss of sensitivity for NaCl between age group 1 (18–39) and age group 2 (40–64). Hermel *et al.*, who used subjects aged 3–60 years, found a

Table 4 Correlation between sensitivities for the ten basic taste compounds for elderly and young people

Elderly	NaCl	KCl	Sucr.	Asp.	Acet.	Citr.	Caffeine	Quinine	MSG
KCl	0.45***							intercorr. = 0.32	
Sucrose	0.40**	0.41***							
Aspartame	0.27*	0.35***	0.30**						
Acetic acid	0.33**	0.23	0.15	0.39***					
Citric acid	0.26*	0.12	0.18	0.29*	0.42***				
Caffeine	0.15	0.18	0.06	0.28*	0.42***	0.45***			
Quinine	0.10	0.31**	0.19	0.25*	0.35***	0.38***	0.39***		
MSG	0.25*	0.27*	0.30**	0.44***	0.54***	0.42***	0.39***	0.26*	
IMP	0.54***	0.38***	0.41***	0.29**	0.36***	0.36***	0.27*	0.23*	0.41***
Young	**NaCl**	**KCl**	**Sucr.**	**Aspa.**	**Acet.**	**Citr.**	**Caffeine**	**Quinine**	**MSG**
KCl	0.15							intercorr. = 0.18	
Sucrose	0.16	0.19							
Aspartame	0.14	0.14	0.33**						
Acetic acid	0.26*	0.20	0.15	0.17					
Citric acid	0.21	0.31**	0.09	0.06	0.29*				
Caffeine	0.16	0.17	0.33**	0.30**	0.20	0.23*			
Quinine	0.15	0.23*	0.27*	0.23*	0.16	0.15	0.36***		
MSG	0.19	0.08	0.34***	0.37***	0.02	–0.03	0.37***	0.36***	
IMP	–0.02	0.13	0.09	0.11	–0.03	0.03	–0.15	0.34	0.07

$*P \leq 0.01$; $**P \leq 0.001$; $***P \leq 0.0001$.

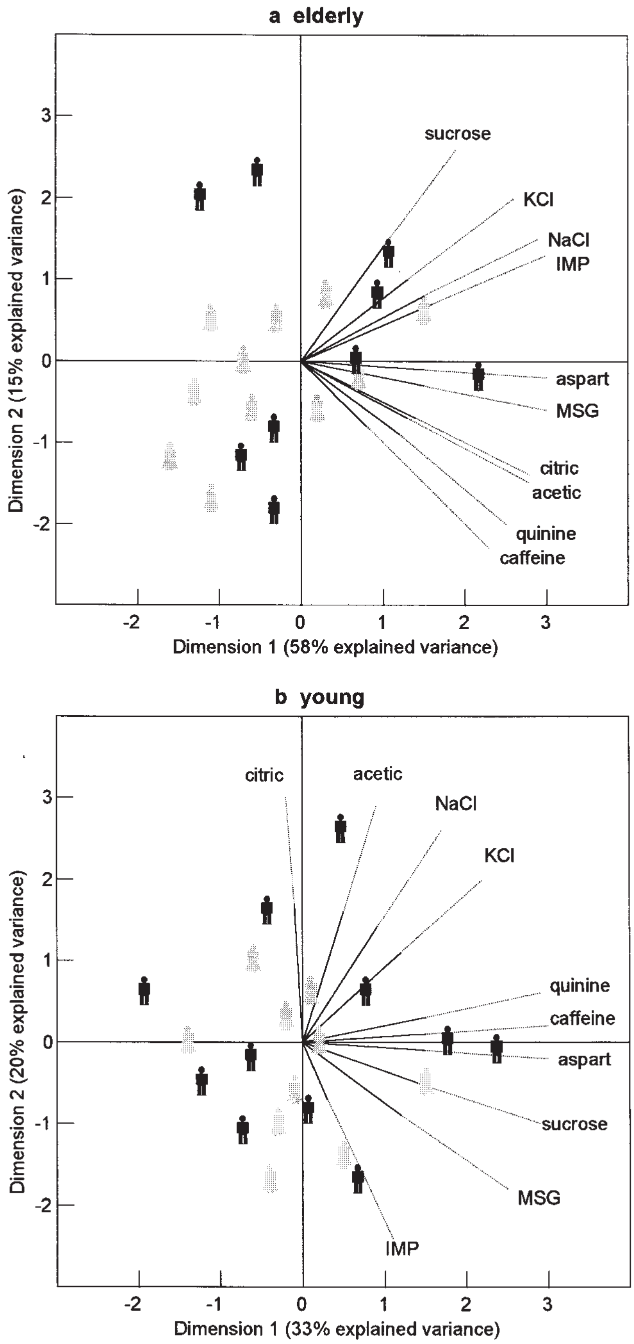

Figure 5 Biplots of the threshold means for ten taste compounds by the elderly **(a)** and the young **(b)** subjects.

decrease in taste acuity with age for sucrose, citric acid and quinine sulphate. However, they did not find a difference in level of sensitivity to salt, but since the presentation of their data on salt contains an obvious error (the percentages of adult subjects recognizing salty taste do not add up to 100, p.41), no conclusion can be drawn on the veracity of their results. In agreement with our findings, a decline in sensitivity with age for NaCl has been found in all the other studies in which salty taste was investigated.

Unlike Schiffman *et al.* (Schiffman *et al.*, 1981), no significant decrease in sensitivity with age was found for aspartame (Figure 2). For quinine HCl we did not find a significant decrease either, as opposed to Bartoshuk *et al.* (Bartoshuk *et al.*, 1986), who also used quinine HCl, and unlike others (Hermel *et al.*, 1970; Weiffenbach *et al.*, 1982; Cowart, (1989; Cooper *et al.*, 1959) who used quinine sulphate in their studies. The fact that our elderly subjects proved to be more PROP-sensitive than our young subjects might explain the difference between our results and the general pattern.

Sensitivity for umami taste has been reported previously (Schiffman *et al.*, 1991). Although only a trend effect of age for MSG ($P = 0.10$) and IMP ($P = 0.11$) was found, the threshold ratios elderly/young in Schiffman *et al.*'s data were 3.14 for MSG and 4.63 for IMP, respectively. In the present study the elderly/young ratio of 1.64 for MSG was much smaller. The difference with the young is somewhat more marked (ratio 1.77) for the elderly men. For IMP the threshold ratio elderly/young of 3.96 is more comparable with the ratio found by Schiffman *et al.*, but again the elderly men needed a higher concentration (ratio elderly men/young 5.70) to detect the difference from the blank. The latter ratio was the highest found in the present study. A number of other studies comparing young and elderly adults have reported differences varying from 2- to 9-fold in threshold concentration. The lack of concordance in these studies is almost certainly due to procedural differences and, in part, to the large variance among the elderly. Another reason could also be the higher drug consumption by the elderly that might influence both taste sensitivity and variance.

Several authors have looked at gender differences in taste threshold studies. The findings of the present study are not in agreement with those of authors who failed to find a gender difference (Cooper, 1959; Hermel *et al.*, 1970; Murphy, 1979; Stevens *et al.*, 1991). Admittedly, the results of the present study were obtained with small samples, but nevertheless showed significant differences and had sufficient power, when the averages of the six replications per subjects were compared. Other authors have found a gender difference for all the taste qualities they investigated. Fikentscher *et al.* (Fikentscher *et al.*, 1977) found that women were more sensitive than men for sodium chloride, cane sugar, citric acid and quinine (sulphate or chloride); this difference became significant beyond the forties. Cohen and Gitman (Cohen and Gitman, 1959) investigated sensitivity to sodium chloride, sucrose, acetic acid and quinine sulphate and found that in general men made more errors in the recognition of taste qualities. In agreement with the results of the present study, these findings seem to indicate that the decline in sensitivity with age is generic in nature and is more severe in men than in women. A few authors, who investigated thresholds for the four primary tastes, have reported gender differences in sensitivity to just one or two substances. Hyde and Feller (Hyde and Feller, 1981) noted that men were less sensitive to sodium chloride than women and Cowart (Cowart, 1989) found that men were less sensitive to sodium chloride and citric acid. In agreement with the present study, the perception of sodium chloride has been found to be more affected by age in men than in women, and more affected than sucrose, citric acid, caffeine and quinine. However, the effect of gender was not always a subject of study (Schiffman *et al.*, 1981, 1991; Bartoshuk, 1986).

The use of different methods and procedures, as outlined in the Introduction, can not only generate differences in threshold values, but can also, in a statistical sense, lead to a difference in sensitivity with age and gender effects. To increase the chance of detecting possible effects of age and gender, in the present study the method of repeated threshold measures was applied. A facilitating effect of practice for olfactory stimuli has been reported previously (Engen, 1960; Rabin and Cain, 1986; Cain and Gent, 1991). Engen found an effect of practice over a rather limited period, after which no further learning occurred, whereas Rabin and Cain found that increments in acuity with experience transferred between odorants, which revealed itself in the fact that for the first three odours investigated there was a learning effect which was not shown for later odours. In contrast to the findings of Engen, the thresholds in the present experiment continued to decrease over all sessions and in contrast to Rabin and Cain, the thresholds decreased to some extent over almost all compounds and continued to do so over all sessions. Since in our experiment there never was a succession of two identical stimuli, whereas Engen presented eight series for one odour per day, interference in the learning process by the succession of stimuli of different quality might explain the difference in findings. The results of Cain and Gent (Cain and Gent, 1991), who also used a procedure in which there was no succession of identical stimuli and who found lowered thresholds for all compounds and for each session, point in the same direction. These authors reported a uniform decline in all thresholds over four sessions of, on average, 25% per session. In a pilot study they also found increments in sensitivity which developed over all five sessions, either with or without feedback. Cain and Gent suggested that 'subjects presumably learn over time to focus more clearly on the stimulus and to separate it from background noise, achieving greater consistency and acuity in the process'.

In our experiment the older men became more sensitive only to citric acid, caffeine and IMP. Thus, an explanation in terms of general learning, for example by moving the solution in their mouth in order to discriminate better, must be excluded. It could be that older men find a way to discriminate specific features of citric acid, caffeine and IMP and thus can detect the tastant at a lower concentration. In contrast, the detection of MSG became even more difficult over time for the older men. We do not have an explanation for this, nor for the fact that young women became less sensitive to IMP over time.

The conclusion of this study must be that there is a general loss with age in taste acuity and in the specificity of taste sensitivity and that men are more prone to losses than women. If these findings are considered as the possible result of impairment in cognitive processes at different levels of information processing, several not mutually exclusive hypotheses based on findings in the literature on vision and audition (Essed and Eling, 1986) could be put forward to explain them. First, the neural noise hypothesis. The signal-to-noise ratio lowered by a decrease in intensity of the signal, by an increase in the level of spontaneously firing neurones, or both, would make it more difficult for the elderly to detect differences between the tastant and the blank. Second, the stimulus persistence hypothesis. If, in the aged nervous system, the neural activity after a taste stimulus lingers longer, the signal-to-noise ratio will be diminished when the following stimulus is presented. Third, the perceptual noise hypothesis is characterized by a decrease in the ability to neglect irrelevant information. The irrelevant information could be considered as a type of noise, but on a psychological/perceptual level and not on a neural level (Stroop, 1935). Fourth, the disinhibition hypothesis. Elderly people could have problems with the selective retrieval of relevant information from memory to connect with new information [disinhibition of irrelevant items (Warrington and Weiskrantz, 1971)]. Fifth, the contextual integration hypothesis. It might be that older people store information in a way less integrated with context than do younger people, with contextual information serving as a tool to separate otherwise similar events. So when older people try to retrieve events from memory, more 'nearly right' candidates will come up as a result of a storage problem.

In our experiment the elderly have a less specified taste acuity than the young, for which the noise hypothesis provides an explanation, either at a neural level, at a psychological level, or at both levels. However, an explanation in terms of physiological ageing cannot be excluded. Although it seems that renewal and redundancy in the taste system preserve gustatory function in old age (Miller and Bartoshuk, 1991), it is not clear that the functioning of aged taste buds is not impaired.

In the group of basic taste stimuli investigated here, the compound with the higher mol. wt is every time the one most prone to a decline in sensitivity with age. Here, this phenomenon remains unexplained, but it might be an interesting lead for future research.

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