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Effect of Concentration on Taste–Taste Interactions in Foods for Elderly and Young Subjects

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Abstract

An increase in concentration of one of the tastants in a 'real food' might affect not only the perception of the taste quality of that manipulated tastant but also the other perceivable taste qualities. The influence of concentration increase of sodium or potassium chloride in tomato soup, sucrose or aspartame in iced tea, acetic or citric acid in mayonnaise, caffeine or quinine HCl in chocolate drink, monosodium glutamate (MSG) or inosine 5′-monophosphate (IMP) in broth on the other perceivable taste qualities in these foods was studied in 21 young subjects (19–33 years) and 21 older subjects (60–75 years). The results showed that for each of these tastants, except for the two acids, increasing the concentration provoked significant positive or negative interaction effects on the perception of one or more other taste qualities of the product. Especially in the young, olfaction plays a larger role in the assessment of taste intensity than has been hitherto assumed. The elderly are less able to discriminate between the taste qualities in a product, whereas the young are more able to do so.

Key words: ageing, cross-modal intensity matching, food, olfactory deprivation, side-tastes

Introduction

Flavours in food consist of a mixture of tastes and odours accompanied by a variety of oral sensations (Pangborn, 1960). Part of the research in this area is focused on mixtures within one sensory modality such as taste (Pangborn, 1960; Kamen *et al.*, 1961; Bartoshuk, 1975; Lawless, 1979, 1982; Gillan, 1983; Van der Heijden *et al.*, 1983; Frank and Archambo, 1986; Kroeze, 1989, 1990; Calviño *et al.*, 1990; Schifferstein and Frijters, 1990; Frank *et al.*, 1993; Schifferstein, 1995; Stevens, 1995; Stevens and Traverzo, 1997; Kaneda *et al.*, 2000; Prescott *et al.*, 2001). The excellent review of taste–taste interactions given by Keast and Breslin (2002) led to the conclusion that in general, suppression may be found with strong stimuli, whereas cases of enhancement may be found mostly with weak, near threshold stimuli.

In another approach the oral perception of mixtures of cross-modal sensory stimuli such as odour and taste mixtures was investigated (Lawless, 1977; Murphy *et al.*, 1977; Murphy and Cain, 1980; Rozin, 1982; Frank and Byram, 1988; Calviño *et al.*, 1990; Shaffer and Frank, 1990; Frank *et al.*, 1993; Stevenson *et al.*, 1999; Kaneda *et al.*, 2000). The use of a specially developed instrument to combine taste with orthonasal instead of retronasal smell (Gillan, 1983; Hornung and Enns, 1984; Enns and Hornung, 1985, 1988) might not show an interaction between taste and smell, since orthonasal sniffing has much weaker effects than retronasal stimulation in the mouth (Zoeteman, 1978). The general picture emerging from this literature is that the interaction effect is strongly dependent on the compounds used. Consonant odours and tastes seem to enhance the perceived taste, dissonant odours and tastes seem either to suppress the perceived taste or to show no effect at all.

Only a few authors investigated age-related taste–taste and odour–taste interaction effects. Hornung and Enns (1984) reported no age-related effects, whereas Murphy (1985), in a study on the ability to identify blended foods while blindfolded, found that the average number of correct responses on the first attempt to identify was significantly higher in young than in old subjects. With feedback and practice, performance improved, but the age effect remained significant. When deprived of olfaction by wearing a noseclip, the young lost their superiority over the elderly.

The experimental questions addressed in the present study are whether the increase of one taste compound in a food, such as sodium chloride, influences the perception of the other tastes of the food, such as the sweetness, sourness, bitterness and umami taste. Furthermore, whether, when such an influence is noticeable, it is different for elderly and young or for men and women. Finally, in this experiment, the role of olfaction in taste will be investigated.

This investigation is part of a larger study in which taste perception with age has been studied with 10 tastants, dissolved in water and in products and assessed by a fixed group of elderly and young subjects wearing a noseclip or not (Mojet *et al.*, 2001, 2003, 2004a,b). The elderly had higher thresholds than the young. While the relative perception (intensity discrimination) seemed to be remarkably resistant to the effects of ageing, the absolute perception (intensity rating) decreased with age for all tastants in water, whereas in product this was only the case for the salty and sweet tastants. Threshold sensitivity predicted neither supra-threshold intensity perception, nor the optimally preferred concentration of the tastants. The latter was not different for the elderly and the young, whereas the former did differ with age for a number of tastants. Apart from the intensities of the taste qualities that were experimentally varied in the food, the intensities of the non-manipulated concentrations of other taste qualities were also assessed. Throughout the present paper these taste qualities (other than the manipulated taste quality in the product) will be referred to as side-tastes.

Although previously we found a decrease in taste sensitivity with age that was generic in nature, there were still differences in taste losses for the different taste qualities—see Table 1, based on results of Mojet *et al.* (2001, 2003).

Thus, when one taste quality is more affected than another taste quality, the perceived interaction between these two taste qualities and thus the integrated perception of the product might be changed for the elderly. When thinking of counteracting the effects of differential taste loss for the sake of the well-being of the elderly, it is essential for the food industry to gain insight in the taste–taste interactions (as well as taste–odour interactions, which are not studied here) for the elderly.

Materials and methods

Subjects

Twenty-one older subjects (age 60–75 years; 10 male, mean = 66.0 years, SD = 3.6; 11 female, mean = 64.6 years, SD = 4.2) and 21 young subjects (age 19–33; 11 male, mean = 26.5 years, SD = 3.6; 10 female, mean = 23.2 years, SD = 3.3) participated in the experiments. They had all taken part in several series of experiments, one on threshold sensitivity (Mojet *et al.*, 2001), one on supra-threshold intensity (Mojet *et al.*, 2003) and one on pleasantness of the same taste stimuli (Mojet *et al.*, 2004a,b). All subjects were Caucasian and met the following criteria: healthy, not on a therapeutic diet, not living in a home for the elderly, not taking any prescribed medicine, non-smoking, no heavy alcohol users, non-pregnant or lactating, not subject to food allergies, good dental hygiene and 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).

Furthermore, since hearing was used as a matching modality for taste, it was made sure that all subjects admitted to the experiments had normal hearing as tested at 750 Hz (for detailed selection criteria, see Mojet *et al.*, 2001). Subjects were recruited by advertisements in local newspapers and on bulletin boards in senior citizen centres. At the end of the experiments the subjects were paid for their participation.

Stimuli

Five taste qualities were investigated: saltiness, sweetness, sourness, bitterness and umami taste. For each taste quality, two representative compounds were chosen, which were administered at five concentrations in commercially available products. The compounds were grouped into two sets, each containing one compound for each of the five taste qualities. One set contained NaCl, sucrose, acetic acid, caffeine and MSG, the other set consisted of KCl, aspartame, citric acid, quinine HCl and IMP.

All tastants, which were of the highest grade of purity available, were dissolved in foods. These food products were iced tea to vary the sweet taste in, chocolate drink to vary the

Table 1 Variance components in% of the total variance in intensity perception to be ascribed to age

	Age	Age × taste quality	Age × compound (within taste quality)	Age × concentration	Age × taste quality × concentration	Age × concentration × compound (within taste quality)	Error
Threshold	93.0	4.0	1.0	–	–	–	2.0
Water	96.4	1.1	0.3	1.0	0.8	0	0.4
Product	92.4	5.6	0.6	0	0.4	0	1.0
Product rated with nose clipped	12.1	60.8	12.4	0	4.8	0	9.9

bitter taste in, mayonnaise to vary the sour taste in, tomato soup to vary the salty taste in and bouillon to vary the umami taste in. The products were versions of commercially available products (all fromUnilever), which were varied by the omission or addition of the tastants to be tested. Five concentration levels of each tastant (ascending 0.2 log steps) were used in the test. An exception in the concentration levels was made for mayonnaise (ascending 0.1 log steps), since the total concentration difference could not be >0.4 log for technical reasons. Since the aim of the experiments was to study age differences in the perception of tastants in normal products rather than to investigate the effect of different tastants on a product, the tastants were embedded in products in which they do occur naturally in normal life and were not all varied in the same product. Furthermore, the second step in the range of five concentrations corresponded to the usual concentration of the compound in each selected product, except in the chocolate drink, where the customary concentration was equal to the first step. Using different products for different taste qualities, helped also to better assess the generality of the age effects in a larger food context.

The compounds were mixed with the dry product beforehand. On the day of testing, the final products were prepared. However, the mayonnaise was prepared beforehand at the Unilever pilot plant at Vlaardingen. The subjects received 20 ml of each stimulus in disposable 50 ml plastic cups. All products were served at room temperature for practical reasons.

The following concentration ranges in (g/l) of the tastants were used: saltiness in tomato soup—sodium chloride 5.68–35.83 and potassium chloride 9.00–56.77; sweetness in iced tea—sucrose 53.95–340.38 and aspartame 0.15–0.92; umami taste in bouillon —MSG 1.58–9.95 and IMP 1.00–6.28; bitterness in chocolate drink—caffeine 0.63–3.98 and quinine HCl 0.01–0.03; sourness in mayonnaise—acetic acid 0.27–0.67 and citric acid 0.02–0.05.

Five levels each of auditory (loudness), visual (size) and kinaesthetic/tactile (weight) stimuli were included to be eventually used as controls in cross-modal intensity matching. As auditory stimuli, 1.5 s bursts of a narrow band of noise centred at 750 Hz were recorded, with intensities varying from 45 to 85 dB in 10 dB steps. These sounds were delivered to the subjects through earphones. As kinaesthetic stimuli, five weights were constructed varying in 0.2 log steps from 33.7 to 212.6 g and hidden in small black (film) containers of equal size which subjects lifted with the top of the forefinger by means of a ring on a string connected to the container. As visual stimuli, an irregular star figure was multiplied in ascending 0.2 log size steps.

Procedure

The first week of this particular experiment, the subjects assessed the stimuli while not wearing a noseclip on three consecutive days, one session per day. The stimuli were presented one after the other. The sip-and-spit method was used, i.e. after tasting, the subjects rinsed their mouth with distilled water and expectorated. For practical reasons separate sessions were held for the elderly and the young. At the start of a session and before each new trial the subject rinsed with distilled water and expectorated. The subjects were instructed to eat a piece of cream cracker at the end of a series of samples of a given compound. In each session of an experiment, all ten compounds were presented once at five concentrations in five series, one for each taste quality. These taste stimuli were alternated with samples of three replications of auditory, visual and weight stimuli at five levels. This alternation prevented monotony and adaptation on the one hand and prolonged the inter-taste-stimulus interval up to 2 min on the other hand, diminishing the induction of fatigue. Before the experiment started the subjects were familiarized with those stimuli by presenting the lowest and highest in the range. Thus, the subjects assessed 50 taste stimuli and 45 cross-modal stimuli in one session. Each session lasted 2 h. Between two taste quality series within a session there was a break of 5 min.

The order in which the taste qualities were presented differed over the 3 days, as did the presentation order of the stimuli within each series. In total, each taste stimulus was assessed three times and each cross-modal stimulus was assessed nine times per experiment. Since the major interest was in unconfounded differences between the two age groups, the presentation order of the compound concentrations and the cross-modal stimuli was the same for all subjects. Possible taste order effects were considered to be strongly reduced by the interspersing of the taste stimuli with the stimuli from the other sensory modalities.

For all taste samples intensity ratings were made of salt, sweet, sour, bitter and umami and on liking, whereas the cross-modal stimuli were rated on intensity only. Intensities were marked on a nine-point scale with the anchors 'very weak' to the left and 'very strong' to the right. For the taste stimuli, liking for the product was assessed on a nine-point pleasantness scale with the anchors 'very little' to the left and 'very much' to the right. Since in the Netherlands it is considered inappropriate by many to admit to food dislike, this scale was considered more appropriate than a like–dislike scale. The second week was similar to the first, but this time the subjects assessed the stimuli while wearing a noseclip.

In this paper the effects of concentration of the tastants that were experimentally varied on the other tastes (side-tastes) of the products are reported.

Statistical analysis

Methods

The statistical analyses are conducted by means of SAS® and SAS/STAT® with data arithmetically averaged over the three replications. Since for the products different tastes were defined as side-taste (e.g. sweet, sour, bitter and umami in tomato soup; sour, salty, bitter and umami in iced tea), Repeated measures analysis is applied separately per product and experimentally varied tastant (e.g. tomato soup with NaCl and with KCl separately), with age, gender and age by gender as between-subject factors and noseclip and concentration as repeated within-subject factors, to investigate the effect of these factors on the perceived side-tastes. Since the sphericity test show that the patterns in the covariance matrix of this experiment generally do not satisfy the Huynh–Feldt condition, the multivariate test results instead of the univariate test results are described, but for the concentration effect only in those cases where the repeated tests resulted in a significant linear or quadratic effect. An interpretation of the results, in terms of higher polynomials, would be rather meaningless.

Levels of significance

All effects that have a P-value of 0.05 or lower are reported 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, a selection of the more interesting effects with a P-value between 0.05 and 0.10 are reported additionally. These effects will be denoted as 'trends'.

Cross-modal intensity matching

All intensity and liking data reported here are based on scores that were corrected by means of the cross-modal intensity matching (CMIM) method, as described in a previous paper from this group (Mojet *et al.*, 2003). Auditory stimulation was selected to correct the present data for differences in scale usage since the sensitivity to low-frequency sounds (~750 Hz) is normally not impaired with age and because an analysis of variance of the results for each of the five sound levels did not show any systematic age or gender variations.

The matrix of the CMIM data consisted of 42 subjects, 27 replications per individual and five different levels of loudness per replication. On average, the standard deviation per individual/level of loudness was fairly constant and of the order of 0.9, indicating that the standard error of an individual/level of loudness combination is in the order of 0.17 ($0.9/\sqrt{27}$). The correction steps were as follows. First, the individual average and the age group average were determined for each sound level. Then, the (individual minus group) averages (which are considered as one obsevation each and thus have a standard deviation of ~0.17 in consequence) were regressed against the group averages using polynomial functions of the latter, starting with a polynomial of degree 0 (constant difference from group mean) and ending with a polynomial of degree 4 (complete fit of individual means). Subsequently, the lowest polynomial with a residual standard deviation of ~0.17 was selected as the assessor's correction formula for each subject. Finally, each individual score on the scale was corrected by a value obtained from the individual's correction formula. All data to be reported here are based on scores that were corrected by means of this method.

Results

Overall age and gender differences

Before analysing the influence of concentration and noseclip on the perception of the side-tastes, first the between-subject effects are considered. This exploration shows a number of significant between-subject effects [all Fs (1,38)]. The elderly perceived both sourness and bitterness as side-tastes of NaCl ($F = 21.45$, $P < 0.0001$ and $F = 8.44$, $P < 0.007$, respectively) or KCl ($F = 16.98$, $P < 0.0002$ and $F = 16.58$, $P < 0.0002$) in tomato soup and of MSG ($F = 8.81$, $P < 0.006$ and $F = 4.10$, $P < 0.05$, respectively) or IMP ($F = 7.89$, $P < 0.008$ and $F = 4.10$, $P < 0.05$, respectively) in bouillon as stronger than the young did. They also perceived bitterness as side-taste in mayonnaise with either acetic acid ($F = 4.99$, $P < 0.04$) or citric acid ($F = 8.07$, $P < 0.008$) as stronger than did the young. However, they perceived sourness in caffeine-flavoured chocolate drink as less intense ($F = 4.36$, $P < 0.05$). Since many tests are conducted, the effects mentioned above and below with a P-value between 0.01 and 0.05 will be considered as indicating a tendency.

In general, no significant gender effects were found for the side-tastes, with the exception of sweetness in KCl-flavoured tomato soup, where men rated sweetness higher than women did [$F(1,38) = 4.31$, $P < 0.05$]. An age by gender effect was found for the bitterness perception of KCl-flavoured tomato soup, where the elderly men and women perceived bitterness as stronger than the young, but where the elderly women did so to an extreme [$F(1,38) = 5.95$, $P < 0.02$]. A second age by gender effect was found for the sourness perception of caffeine-flavoured chocolate drink [$F(1,38) = 5.71$, $P < 0.03$]. Here, the young women perceived sourness most strongly, followed by the young men, the older men and the older women. Since only a few gender differences were found, the mean intensities of all rated taste qualities are given in Figures 1 and 2 per experimentally varied tastant for elderly and young only.

Influence of concentration of the varied tastant on the perception of the side-tastes

Is perception of side-tastes dependent on the concentration of the experimentally varied taste and if so, do elderly and young or men and women differ in this respect? Apart from some differences, which will be discussed later, the effects of the manipulation on the intensity of the side-tastes (see Figures 1 and 2) show a strong similarity for both noseclip conditions and are always in the same direction. Taken over both conditions, increasing the concentration of both salts NaCl and KCl, induced a significant [all Fs (4,35)] decrease in sweetness of tomato soup ($F = 9.31$, $P < 0.0001$ and

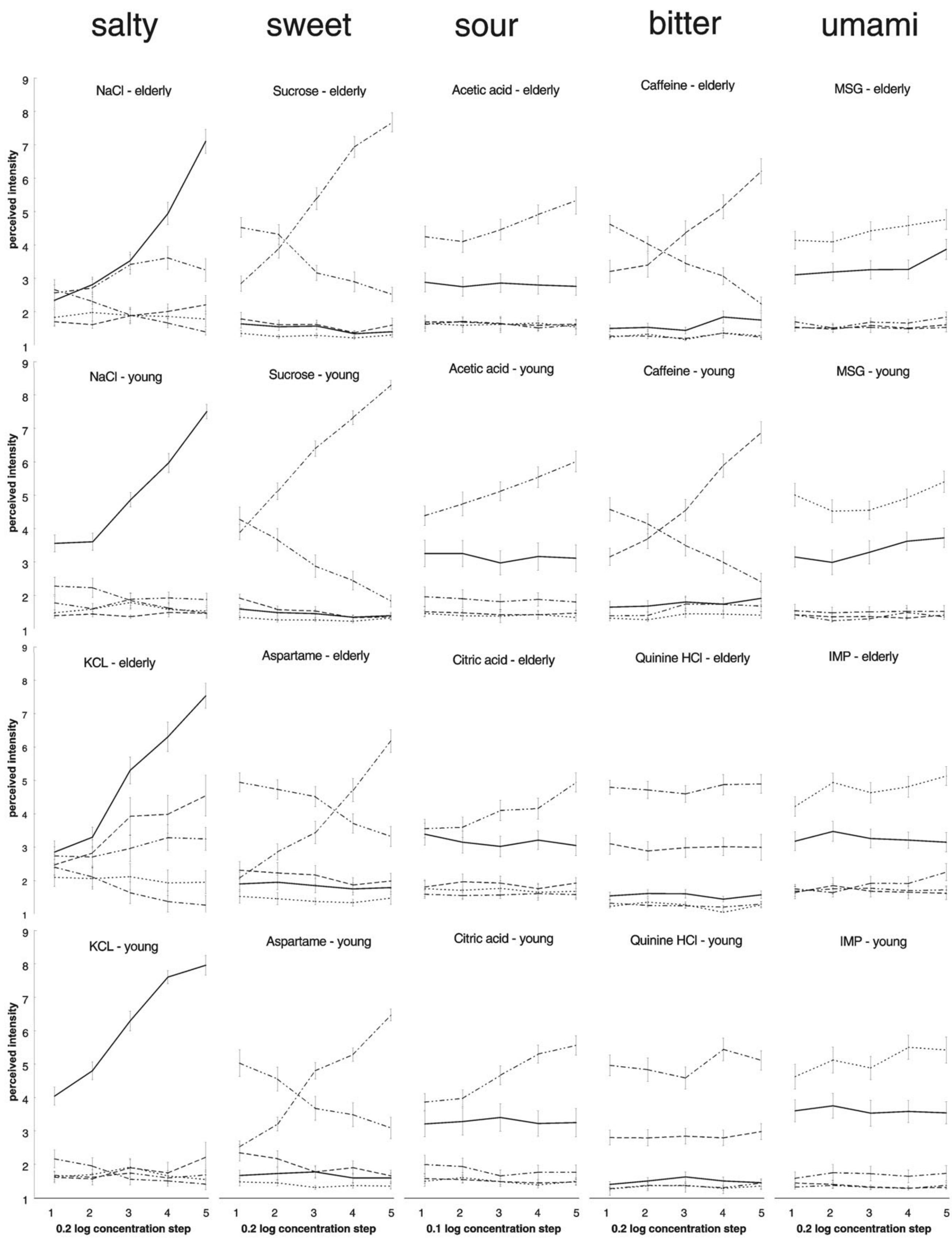

Figure 1 Perceived intensities of all taste qualities for elderly and young, while not wearing a noseclip. Saltiness is represented by solid lines, sweetness by lines of alternating stripes and dots, sourness by lines of stripes and double dots, bitterness by striped lines and the taste of umami by dotted lines.

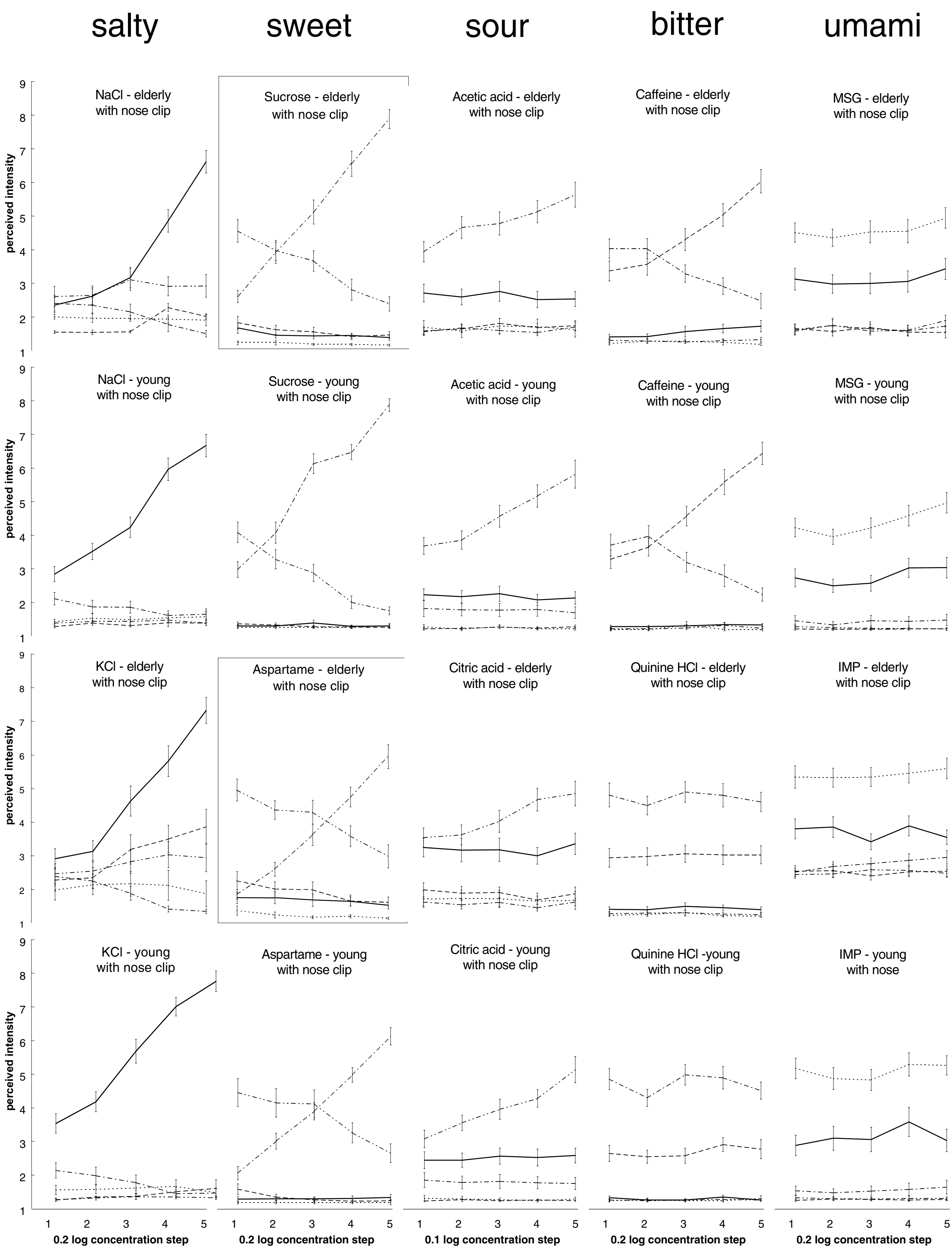

Figure 2 Perceived intensities of all taste qualities for elderly and young, while wearing a noseclip. Saltiness is represented by solid lines, sweetness by lines of alternating stripes and dots, sourness by lines of stripes and double dots, bitterness by striped lines and the taste of umami by dotted lines.

$F = 9.07$, $P < 0.0001$, respectively), but significant increases in bitterness ($F = 3.10$, $P < 0.03$ and $F = 6.91$, $P < 0.0003$), sourness ($F = 8.70$, $P < 0.0001$ and $F = 2.31$, $P < 0.08$, trend only) and umami taste ($F = 2.69$, $P < 0.05$, KCl only). The increases in sourness with increasing NaCl and in bitterness with increasing KCl are larger for the elderly than for the young ($F = 4.01$, $P < 0.009$ and $F = 4.72$, $P < 0.004$, respectively).

The increase in sucrose and aspartame concentration in iced tea resulted in significant [all *F*s (4,35)] decreases in bitterness ($F = 3.92$, $P < 0.01$ and $F = 6.59$, $P < 0.0005$, respectively), major decreases in sourness ($F = 48.06$, $P < 0.0001$ and $F = 30.67$, $P < 0.0001$, respectively) and a minor decrease in saltiness (sucrose only; $F = 2.94$, $P < 0.04$). The decrease in bitterness with increasing aspartame was larger for the young than for the elderly ($F = 5.17$, $P < 0.003$).

The increasing concentration of neither of the acids in mayonnaise had a significant influence on the perception of side-tastes and the slopes of the side-tastes also did not differ for the elderly and young.

An increase in caffeine and quinine provoked a decrease in sweetness of chocolate drink, which was large with caffeine ($F = 55.44$, $P < 0.0001$) and less pronounced with quinine ($F = 3.93$, $P < 0.01$).

An increase in MSG concentration in broth is accompanied by an increase in saltiness ($F = 16.86$, $P < 0.0001$), whereas an increase in IMP led to an increase in saltiness ($F = 4.18$, $P < 0.007$) and in sweetness ($F = 4.23$, $P < 0.007$).

The elderly and young did not differ in the slopes of side-tastes in mayonnaise, chocolate drink or broth. Men and women did not show significant differences in their slopes for any of the side-tastes in any of the products.

Deprivation of olfactory stimulation

To investigate whether in this experiment olfaction played a role in taste perception, the noseclip conditions (off and on) were compared. Significant differences were found in the perception of side-tastes [all *F*s (1,38)]. Generally, clipping the nose resulted in a lower level of intensity ratings: lower sourness and bitterness ratings of tomato soup with NaCl ($F = 10.02$, $P < 0.003$ and $F = 6.32$, $P < 0.02$, respectively) or of tomato soup with KCl ($F = 9.71$, $P < 0.004$ and $F = 12.96$, $P < 0.0009$, respectively); lower ratings of saltiness, bitterness and umami taste in iced tea with sucrose ($F = 4.79$, $P < 0.04$, $F = 8.02$, $P < 0.008$ and $F = 6.64$, $P < 0.02$, respectively) or with aspartame ($F = 6.20$, $P < 0.04$, $F = 12.80$, $P < 0.001$ and $F = 9.20$, $P < 0.005$, respectively); lower ratings of saltiness in mayonnaise with acetic or with citric acid [$F = 8.35$, $P < 0.007$ and $F = 3.97$, $P < 0.06$ (trend), respectively]; lower ratings of sourness and saltiness in chocolate drink with caffeine ($F = 7.42$, $P < 0.01$ and $F = 9.82$, $P < 0.004$, respectively) or with quinine ($F = 4.41$, $P < 0.05$ and $F = 10.76$, $P < 0.003$, respectively); and lower saltiness ratings of broth with MSG ($F = 8.39$, $P < 0.007$) or with IMP ($F = 5.61$, $P < 0.03$).

These reductions in perceived intensities are mainly due to higher intensity ratings given by the young in the 'noseclip off' condition than in the 'noseclip on' condition. *t*-Tests showed that the differences between the 'noseclip off' and the 'noseclip on' condition only deviated significantly from zero for the elderly when tested over all tastants and all side-tastes [$T(20) = 2.18$, $P < 0.04$]. This is also shown in the scatter plots of Figure 3a and b. The ratings of the elderly shown in Figure 3a are almost similar in the two noseclip conditions (on and off), which is shown by the close proximity of the ratings to the $y = x$ line. The variance in the group of elderly is much larger than the variance in the group of young subjects, whose ratings are, compared to the elderly, more scattered over the left upper side of the plot. This indicates that the young make more use of their sense of smell when assessing the intensities in the 'noseclip off' condition than the elderly. In all forty cases (10 tastants, four side-tastes each, averaged over the five concentrations), the young gave lower ratings when wearing a noseclip than when not wearing a noseclip. Furthermore, in all cases but one, these differences between the 'noseclip on' condition and the 'noseclip off' condition, were larger than the differences found for the elderly (overall sign test: $P < 0.0001$). The only exception was found for the bitterness of tomato soup with KCl, where no significant difference between the elderly and the young was found, but where the elderly women perceived stronger bitterness when they wore no noseclip than when they wore one. This difference between the two conditions was the only difference found for one of the age by gender groups that deviated significantly from zero [$T(10) = 3.15$, $P < 0.02$].

Analysed per individual side-taste for each of the experimentally varied tastants, the interaction between noseclip and age reached significance [all *F*s (1,38)] in 10 out of these forty cases.

Thus, different effects of the noseclip condition on the ratings of the elderly and young were found for bitterness of iced tea, mayonnaise and bouillon, but not of tomato soup. With the noseclip on, the extent to which the young gave lower ratings to side-tastes than the elderly, was larger than

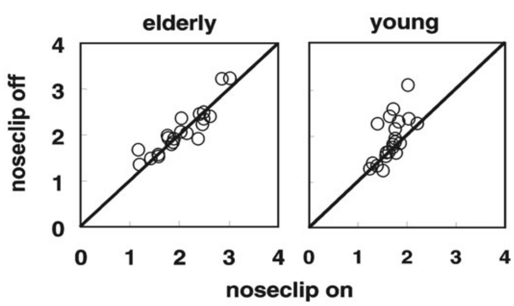

Figure 3 Scatter plots of the intensities of the side-tastes of the five products, assessed by elderly and young while wearing a noseclip or not. The intensities are averaged per person over all concentrations and all side-tastes.

when they had no noseclip on. This age by noseclip interaction on bitterness was found for broth with MSG ($F = 7.26$, $P < 0.02$), for mayonnaise with acetic acid ($F = 5.47$, $P < 0.03$) or citric acid [$F = 3.28$, $P < 0.08$ (trend)], for iced tea with aspartame ($F = 4.97$, $P < 0.04$), or sucrose ($F = 5.64$, $P < 0.03$). An interaction effect was also found in the ratings of sweetness of bouillon with MSG ($F = 6.18$, $P < 0.02$), where, when wearing a noseclip, elderly subjects gave higher ratings than young subjects. Furthermore, wearing a noseclip had also a different effect on elderly and young in the assessment of saltiness of mayonnaise with acetic acid ($F = 4.47$, $P < 0.05$) or citric acid ($F = 4.98$, $P < 0.04$) and of chocolate drink with caffeine ($F = 6.08$, $P < 0.02$). With the noseclip off, the young gave higher ratings than the elderly, whereas with the noseclip on the reverse was true. A similar interaction was found in the assessment of sourness of chocolate drink with caffeine ($F = 10.05$, $P < 0.03$) or with quinine ($F = 5.84$, $P < 0.03$) where with the noseclip on, the young gave higher ratings than the elderly.

Deprivation of olfaction had no different effect on the ratings of men and women, or on those of the four age by gender groups.

In a few cases, wearing a noseclip had also an effect on the slopes of the side-tastes [all *F*s (1,38)]. Both, the slopes of the sweet and the sour taste of tomato soup with increasing NaCl were significantly flatter when subjects wore a noseclip (sweet, $F = 12.07$, $P < 0.002$ and sour, $F = 11.33$, $P < 0.002$). Furthermore, the sweetness slope of chocolate drink with increasing caffeine was significantly flatter ($F = 8.67$, $P < 0.006$) when the assessment was made with the nose clipped. Wearing a noseclip also led to a flatter slope ($F = 3.08$, $P < 0.09$, trend only) of sweetness in chocolate drink with increasing quinine.

Discussion

Interactions

This first study over all taste qualities in the same group of elderly and young people shows that increasing the concentration of one dominant taste compound in a complex food matrix has different effects on the perceived intensities of side-tastes of the food. In addition, these effects were similar for the two tastants within one taste quality. Since in this experiment, foods were chosen on the basis of their representativeness of salty, sweet, sour, bitter and umami foods in 'real life', different foods were used to investigate the effects of the manipulated tastants on the side-tastes and as a result no mutual effects between the taste qualities in one system can be demonstrated.

Nevertheless, a generalization of the taste–taste interaction effects over these different food types might help to further the insight in these complex interactions. Figure 4, which is a schematic overview of the results and is inspired by Keast and Breslin (2002), summarizes this generalization. They divide the taste–taste interaction effects found in the literature into three schemata's, one for low, one for medium and one for high intensity/concentrations. The concentrations of the varied tastants in the present experiment lie in the same range as that which is found in normal every day food. One could argue that experiments with much higher concentrations bear little relevance for every day life and run the risk of introducing artefacts caused by the strong deviation from what subjects are used to.

The effects caused by the experimentally varied tastants in the present study correspond mainly with the Keast and Breslin (2002) medium concentration scheme. It should be noted that in Figure 4 the arrows pointing away from a given taste quality are directly comparable since they are effects exerted in the same food matrix, whereas the arrows coming towards a certain taste quality show how this quality is affected by changes of other taste qualities in different food matrices.

In contrast to the findings presented by Keast and Breslin (2002), no effect of acids on any of the other taste qualities was found in the present experiment. This lack of suppression or enhancement effect might be due to the relatively limited concentration range in which the highest concentration was only 2.5 times larger than the lowest concentration. Another difference exists with regard to the influence of salts on bitterness. In their summary Keast and Breslin describe this influence as suppressive, irrespective of the used concentration, whereas in the present study an increase in bitterness was found for both salts. Finally, in the present study, neither an increase nor a decrease in sourness by bitter tastants, as Keast and Breslin (2002) described for the moderate and high concentrations respectively, was found. This could be due to the fact that the sourness perceptibility

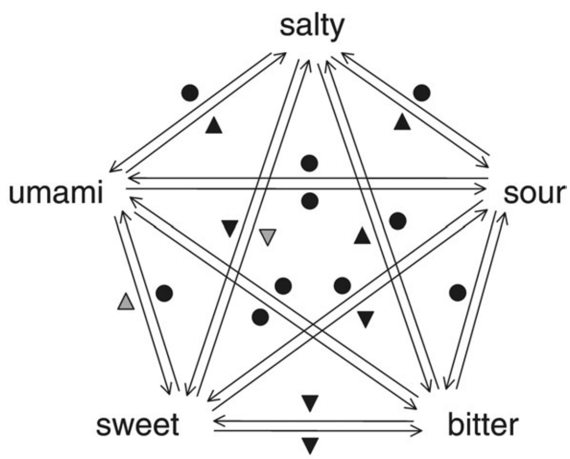

Figure 4 Pentagram of the taste–taste interactions in complex food matrices. Outgoing arrows show the influence of one taste quality on the other taste qualities in the same food. Incoming arrows represent influences of different taste qualities from different foods. Triangles indicate either an enhancement effect (when they point upwards) or a depressive effect (when they point downwards). Circles indicate a nil effect. Black symbols represent both tastants within a taste quality, grey symbols indicate that only one of the tastants exerts the effect.

in the chocolate drink was very low to begin with, or it might be that the concentration range used here falls just between the moderate and high intensities for which Keast and Breslin (2002) describe opposite findings.

Umami perception was not influenced by any of the other taste qualities, which supports the findings of Bartoshuk (1975). She found that substances which show the least compression when added to themselves, like the umami tastants do (see Figures 1 and 2), also show the least suppression when other substances are added to them.

Slopes of the side-tastes with age

Taste–taste interaction effects have not been studied in elderly to our knowledge, whereas odour–taste interactions are reported by Enns and Hornung (1985) who found that, when using odorant/tastant pairs, the magnitude of suppression [overall intensity/(smell intensity + taste intensity)] was not affected by the age of the subjects. In the present experiment only in 3 out of the possible 40 cases (sourness with NaCl and MSG, bitterness with KCl) a steeper increase was found for the elderly than for the young and in only one case a more pronounced decrease in bitterness with increasing aspartame was found for the young. This suggests that the slopes of the perceived side-tastes are not systematically affected by age.

Contribution of olfaction

No findings on the influence of the contribution of olfaction on taste–taste interactions have been reported in the literature. However, Murphy (1985) reported that, when deprived of olfaction the performance of young women, in a task where they had to identify blended foods, fell to the same level as that of elderly women. Obviously, when they did not wear a noseclip, the young women took more advantage of their sense of smell. Furthermore, it suggests that a decline in olfactory sensitivity of the elderly women made them perform less well than the young in this task with both olfactory and taste cues.

Would the same phenomenon occur in the present experiment where the side-taste intensities had to be assessed? In line with a previous study (Mojet *et al.*, 2003), the differences between the 'noseclip off' and 'noseclip on' condition were larger for the young than for the elderly in the present experiment. Since the overall difference between the with and without smell condition deviated not only significantly from zero for the young but also (significantly, but to a minor degree) for the elderly, it is clear that they too use their sense of smell, if to a lesser degree. As was pointed out in a previous paper (Mojet *et al.*, 2003), there are two possible ways in which smell could play a role. First, the tastants themselves might have a smell. To the knowledge of the present authors, this possibility, unlikely as it seems for most tastants with the exception of acetic acid, has never been tested seriously. In the second place, the presence of the tastants might interact with the olfactory perception of the medium in which they are presented, which is known as a 'salting out' effect (Segatin and Kiofutar, 2000). That this latter possibility exists when the tastants are presented in product is evident, since some of them (MSG and IMP) are known flavour enhancers but might this also be true in the case of water? It would suggest that water has a smell of its own which is changed by tastants. To clarify this point, further research has been carried out (Mojet and Köster, 2004) and its findings favour the idea that the tastants have a smell that is perceptible when they are dissolved in water.

Age differences in taste quality discrimination ability

One interesting general finding has to be discussed here. Over all products and tastants, the elderly gave higher ratings to the perceived intensities of the side-tastes than did the young, whether their olfactory input was blocked (37 out of 40 cases) or was not blocked (29 out of 40 cases). This is remarkable, since previously it was found (Mojet *et al.*, 2003) that the elderly rated the perceived intensities of the experimentally varied taste lower than the young in 9 out of 10 cases (sign-test, $P < 0.02$) without wearing a noseclip and in 6 out of 10 cases (n.s.) while wearing a noseclip.

To show this age difference in the perception of the side-tastes graphically, the ratio between the scores for the dominant taste and for the summated side-tastes are given in Figure 5, in percentages of all scores. For example, the percentage of all scores that is given to saltiness in tomato soup with NaCl increases from 21.3% (concentration step 1) to 45.1% (concentration step 5) for the elderly and from 33.3 to 54.4% for the young, whereas per definition, the percentage given to the combined side-tastes decreases from 78.7 to 54.9% for the elderly and from 66.7 to 45.6% for the young. It seems that the young are better able to discriminate between the different taste qualities than the elderly. This is especially so in the case of tomato soup. Whether this is because tomato soup is more complex than the other products used, or because the taste quality varied experimentally was salty, can not be concluded from this experiment. That the elderly discriminate to a lesser degree between the taste qualities was shown to some degree for all products with the exception of chocolate drink with quinine, where both the elderly and the young perceived the side-tastes rather strongly and where the young consistently did so to a higher degree. Previously, it was found that the elderly have a less specified taste acuity than the young, meaning that at threshold level the sensitivities for the 10 tastants were more strongly correlated for the elderly than for the young (Mojet *et al.*, 2001) and that at supra-threshold level, the inter-correlation of all tastants dissolved in water and in product was higher for the elderly than for the young (Mojet *et al.*, 2003).

For the phenomena described above, which both point in the direction of a possible impairment in cognitive processes (Essed and Eling, 1986), the noise hypothesis might provide an explanation, either at a neural level, or at a psychological

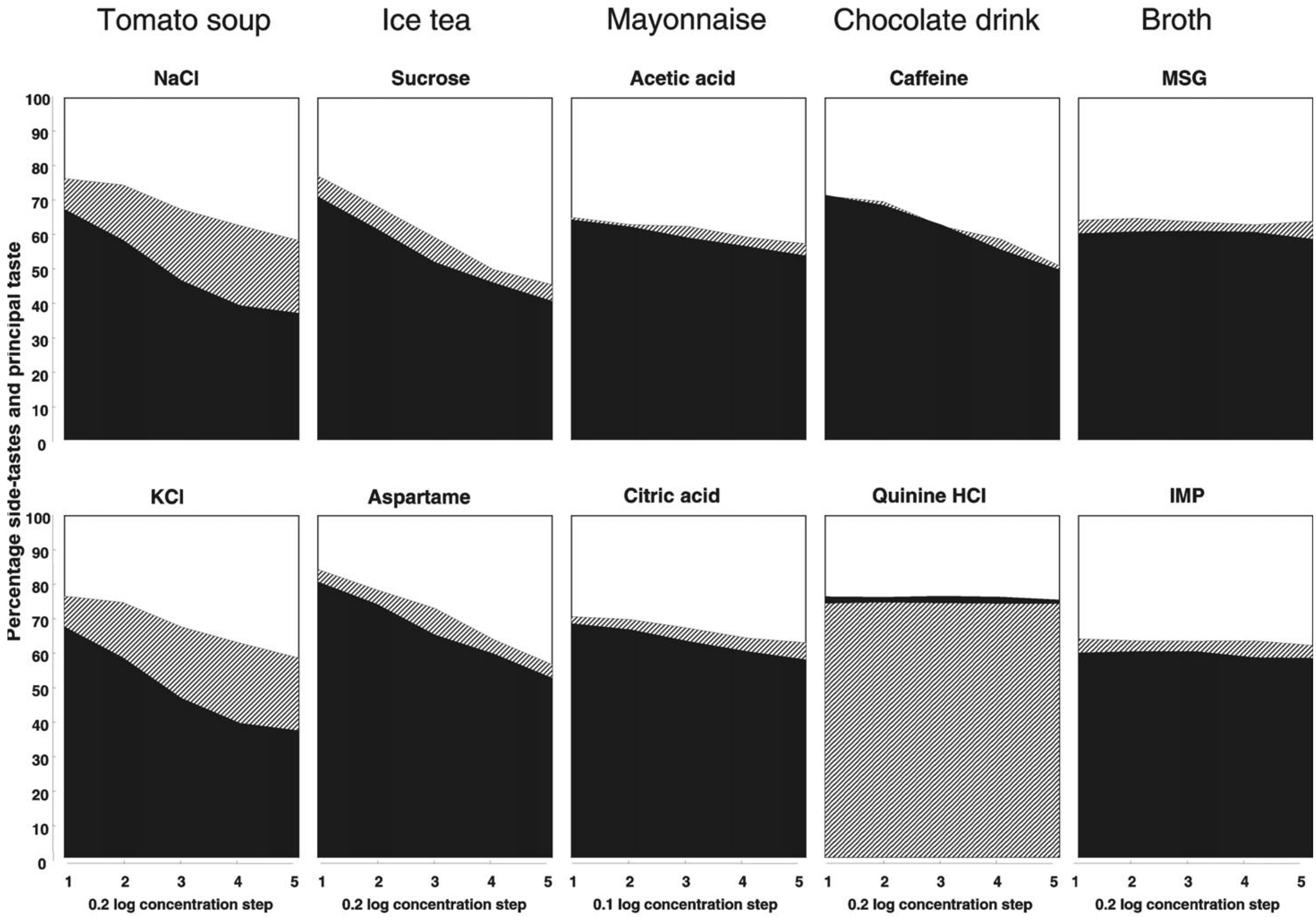

Figure 5 Percentages of the sum of intensity scores given to the dominant taste and to the combined side-tastes for elderly and young subjects. The percentages of scores given by young subjects to the combined side-tastes are represented by the black areas, while the grey or striped areas (including the black areas) show the percentages for the elderly (except for quinine, where the young attributed a higher percentage of their scores to the side-tastes than the elderly). The white areas represent the percentage of intensity scores given to the dominant taste for the elderly. For the young the white and striped area represent the percentages given to the dominant taste (reversed for quinine).

level. The neural noise hypothesis supposes that the signal to noise ratio is lowered by a decrease in intensity of the signal, by an increase in the level of spontaneously firing neurons, or both and thus would make it more difficult for the elderly to differentiate between the requested taste quality and the other taste qualities. 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).

The present experiment reveals three points of interest for further research. First, it can be concluded that increasing the concentration of the dominant taste in foods provokes significant positive or negative interaction effects on the perception of one or more other taste qualities of the product that are not age-related in most cases. Whether this influence is tastant or product specific, or both, is a subject for further research. Secondly, the fact that, especially in the young, olfaction plays a larger role in the assessment of taste intensity than has been hitherto assumed, also has to be investigated further. Finally, the finding that the elderly are less able to discriminate between the taste qualities in a product, whereas the young are more able to do so, has not been reported previously and should be pursued in future research because of its possible gerontological implications.

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