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Perception of Trigeminal Chemosensory Qualities in the Elderly

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Abstract

One hundred healthy elderly subjects (65–88 years) were tested for their ability to: (i) assign verbal labels from a list of trigeminal type descriptors to six odorants known to have a strong trigeminal component; (ii) discriminate between intensity-matched pairs of these odorants in an odd-ball paradigm. Their performance was compared with that of 100 young controls (23–36 years). Young controls judged menthol and cineole as distinctly cool and fresh, acetic cid as pungent and sour and acetone as pungent, but showed no clear descriptive profile for ethanol and propanol. The descriptive profiles given by the elderly subjects correlated significantly with those given by the young controls for all six odorants and thus indicate a high degree of conformity in trigeminal perception of chemosensory qualities between the two age groups. In the odd-ball test the young controls correctly discriminated an average of 8.0 of 9 stimulus pairs presented, with most mistakes occurring in response to pairs with a similar trigeminal profile. With an average of 6.4 of 9 items correct, the discrimination performance of the elderly subjects was significantly poorer than that of the young controls but nevertheless significantly above chance at the group level with all 9 stimulus pairs. These results suggest that the nasal trigeminal system may experience some degree of age-related impairment but still contributes considerably to the perception and discrimination of chemosensory qualities in the elderly.

Introduction

A number of studies have demonstrated that aging is associated with a decline in virtually all aspects of olfactory performance. Age-related smell impairments include deficits in absolute olfactory sensitivity, odour discrimination, odour identification or recognition and odour memory (Doty, 1991; Weiffenbach, 1991; Murphy *et al.*, 1997; Schiffman, 1997; Larsson and Bäckman, 1998; Lehrner *et al.*, 1999). Furthermore, aging is associated with a loss of suprathreshold intensity perception (Stevens and Cain, 1985) and with a greater susceptibility to olfactory adaptation and a slower recovery from such adaptation (Stevens *et al.*, 1989).

It is also well established that the vast majority of odorants have, at least at high concentrations, some trigeminal stimulating properties (Doty, 1995) and nasal trigeminal function is increasingly recognized as an integral part of human chemosensory perception (Hummel, 2000). However, surprisingly few studies to date have directly assessed age-related changes in nasal trigeminal function or tried to distinguish between olfactory and nasal trigeminal impairments as a function of age. Stevens and Cain determined detection thresholds for CO_2, an odorless chemosensory stimulus which arouses trigeminally mediated irritation in the nose, and found no significant difference between young and elderly subjects (Stevens and Cain, 1986). The same authors, however, also reported a strong elevation of the threshold of apnea and a marked weakening of perceived CO_2 suprathreshold strength in the elderly subjects.

Testing the ability of subjects to localize the side of monorhinal stimulation (von Skramlik, 1926; Kobal *et al.*, 1989), Wysocki *et al.* reported an age-related decline in nasal trigeminal sensitivity which, however, was much less pronounced compared with the decline in olfactory sensitivity with advancing age (Wysocki *et al.*, 1997). Stevens *et al.* found a larger reduction in perceived stimulus magnitude with age in response to suprathreshold concentrations of isoamyl butyrate, a non-irritating odorant, compared to CO_2, a non-odorous irritant (Stevens *et al.*, 1982). Further, the authors concluded that olfactory and nasal trigeminal losses seem to be unrelated as a significant proportion of their elderly subjects showed good olfactory sensitivity and poor trigeminal sensitivity, and *vice versa.* More recently, Hummel *et al.* recorded chemosensory event-related potentials (CSERPs) in response to stimulation with olfactory or nasal trigeminal stimuli in three different age groups and reported the age-related decrease in CSERP amplitudes in response to the former to be more pronounced than to the latter (Hummel *et al.*, 1998).

Testing the ability of congenitally anosmic subjects to assign verbal labels from a list of trigeminal type descriptors to six odorants known to have a strong trigeminal component and to discriminate between intensity-matched pairs of these odorants in an odd-ball paradigm, Laska *et al.* have recently shown that the nasal trigeminal system may not only contribute to the perception of chemosensory intensity (Cain, 1974) but also to that of chemosensory quality as the descriptive profiles given by anosmic subjects and normosmic controls showed a considerable degree of conformity between the groups and thus confirmed the existence of trigeminally mediated qualities such as pungent, cool, stinging, burning, etc. (Laska *et al.*, 1997). Further, the authors demonstrated that the nasal trigeminal system may also contribute substantially to chemosensory discrimination as the performance of the anosmic subjects in the odd-ball test was only slightly poorer than that of normosmic controls.

To the best of my knowledge no study to date has directly assessed age effects on trigeminal perception of chemosensory quality. Therefore, I employed the test developed by Laska *et al.* (Laska *et al.*, 1997) with a group of 100 elderly subjects and compared their performance with that of a group of 100 young controls. Specifically, I addressed the following questions: (i) do elderly subjects differ from young controls in their use of trigeminal type verbal labels to describe odorants known to have a strong trigeminal component; (ii) do elderly subjects show an impaired ability to discriminate between such odorants?

Materials and methods

Subjects

A total of 100 community dwelling elderly subjects (65–88 years of age, 71 females and 29 males; Figure 1) and 100 young control subjects (23–36 years of age, 50 females and 50 males) with no history of olfactory dysfunction participated in the study. All subjects were in good general health and assessed for use of medication (number of medicaments taken per day) and smoking habit (number of pack years and actual or former smoker). All elderly subjects had successfully completed the Mini Mental State Test (MMST) (Folstein *et al.*, 1975) and thus showed no obvious impairment in their global level of cognitive functioning. Gender and age distribution of the group of elderly subjects are shown in Figure 1.

Odorants

A set of six odorants known to have a strong trigeminal component (Doty *et al.*, 1978; Doty, 1995; Laska *et al.*, 1997) and presumed to represent three distinct trigeminal qualities (von Skramlik, 1926) was used (Table 1). In an attempt to ensure that odorants were of approximately equal strength, intensity matching was performed by a panel of six young subjects using a saturated aqueous solution of (–)-menthol as standard and following a standardized and widely used procedure (ASTM, 1975). Thus, all odorants were well above threshold for young controls and likely to be perceptible for elderly subjects.

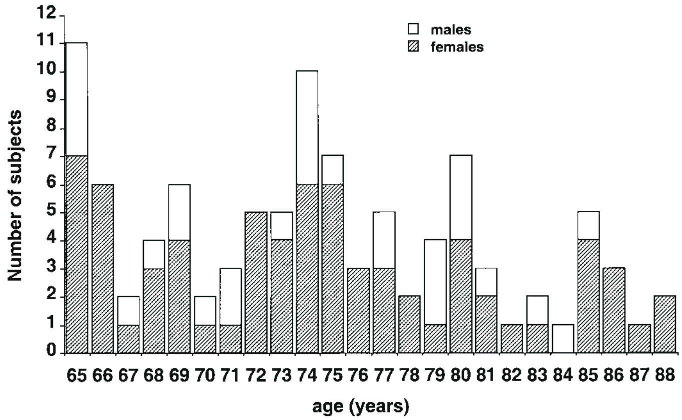

Figure 1 Gender and age distribution of the group of elderly subjects.

Table 1 Substances and concentrations used for the stock solutions

	Substance	Concentration	Odour quality	Trigeminal quality[a]
1	(–)-Menthol[b]	saturated aqueous solution	peppermint	cool, fresh
2	1,8-Cineole[c]	undiluted	eucalyptus	cool, fresh
3	Acetic acid[b]	1:30 aqueous solution	vinegar	pungent, painful
4	Acetone[c]	undiluted	nail polish remover	pungent, painful
5	Ethanol[b]	undiluted	alcohol	warm, burning
6	n-Propanol[b]	undiluted	disinfectant	warm, burning

[a]According to von Skramlik (von Skramlik, 1926).

[b]Supplied by Merck.

[c]Supplied by Sigma.

Stimulus delivery

A 40 ml aliquot of each odorant was presented in a 250 ml polyethylene squeeze bottle equipped with a flip-up spout which for testing was fitted with a hand-made Teflon nose piece. Subjects were instructed as to the manner of sampling and at the start of the session were allowed time to familiarize themselves with the bottles and the sampling technique. Care was taken that the nose piece was only a short distance (1–2 cm) from the nasal septum during sampling of an odorant in order to allow the stimulus to enter both nostrils. To prevent ocular and oral trigeminal irritation from providing additional sensory information subjects were asked to sample the odorants with their eyes and mouth closed. Each bottle could be sampled twice with an interstimulus interval of at least 10 s. Sampling duration was restricted to 1 s per presentation in order to minimize adaptation effects and adsorption of odorants on the facial skin of the subjects.

Test procedure

Subjects were tested for their ability to (i) assign verbal descriptors to odorants and (ii) discriminate between odorants as follows.

Descriptive profiles

Subjects were successively presented with six odorants (Table 1) and asked to choose the three adjectives best describing each odorant from a list of 17 trigeminal type descriptors (Table 2) and to rank their three choices according to suitability. The order of stimulus presentation was always menthol, acetic acid, ethanol, cineole, acetone, propanol in order to avoid successive presentation of odorants which according to von Skramlik evoke the same trigeminal quality (von Skramlik, 1926).

All adjectives listed in Table 2 were used by von Skramlik to describe sensations which he believed to be mediated by the nasal trigeminal system (von Skramlik, 1926). In order to minimize the possibility of semantic ambiguity all subjects were explicitly asked if they had difficulty interpreting any adjective in the list and in the very few cases in which subjects were uncertain about the meaning of a particular descriptor they were given appropriate information.

Discrimination

In nine further tests, always conducted in the order listed below, subjects were asked to compare three bottles and to identify the one containing the *odd stimulus* (given in italic): 1. (–)-menthol versus *ethanol*; 2. propanol versus *acetone*; 3. acetic acid versus *(–)-menthol*; 4. ethanol versus *propanol*; 5. acetone versus *1,8-cineole*; 6. ethanol versus *acetic acid*; 7. (–)-menthol versus *1,8-cineole*; 8. acetic acid versus *acetone*; 9. 1,8-cineole versus *propanol*. After each decision subjects were asked whether their choice was predominantly based on perceived differences in stimulus quality or on perceived differences in stimulus intensity.

Preliminary tests indicated the discrimination task to be quite strenuous, particularly for the elderly, and thus only 9 of the 15 possible stimulus pairs were presented. Care was taken to: (i) present subjects both with odorant pairs assumed to have similar trigeminal qualities (items 4, 7 and 8) and pairs assumed to have different trigeminal qualities (items 1–3, 5, 6 and 9, with each of the six odorants presented as odd stimulus in one of the items and as even stimulus in another item); (ii) avoid presenting the same odorant in successive stimulus pairs.

Data analysis

Descriptive profiles were analysed in three ways: (i) the frequency of all namings per odorant was calculated for each group and expressed as a percentage relative to the number of subjects per group; (ii) the three namings per odorant and subject were weighted by assigning three points to the first mentioned adjective, two points to the second and one point to the last mentioned descriptor and these points then summed for each group; (iii) only the descriptors which were first mentioned, i.e. presumably best describing the odorant, by each subject in response to each odorant were considered.

Table 2 List of trigeminal type verbal descriptors[a]

1. Pungent (*stechend*)	7. Warm (*warm*)	13. Fresh (*frisch*)
2. Burning (*brennend*)	8. Scratching (*kratzend*)	14. Sweet (*süßlich*)
3. Painful (*schmerzhaft*)	9. Tickling (*kitzelnd*)	15. Salty (*salzig*)
4. Sharp (*scharf*)	10. Prickling (*prickelnd*)	16. Bitter (*bitter*)
5. Astringent (*zusammenziehend*)	11. 'Sneeze' (*Niesreiz-erregend*)	17. Sour (*sauer*)
6. Furry (*pelzig*)	12. Cool (*kühl*)	

[a]The original German is given in parentheses.

Preliminary analyses revealed that all three methods of obtaining descriptive profiles led to similar results which significantly correlated with each other. However, while subjects usually had few difficulties in assigning descriptors to each odorant, many participants, the elderly in particular, had some difficulty in ranking their three choices according to suitability. Therefore, the results obtained from method (i), all namings per odorant, were used for statistical comparisons.

Comparisons between descriptive profiles derived from the labelling of odorants were performed using the Spearman rank correlation coefficient and tested for significance by computing t values. Frequencies in discrete categories were compared using the χ^2 test and deviations from a chance distribution of correct decisions were calculated using the binomial test corrected for continuity (Siegel and Castellan, 1988). All tests were two-tailed and, if not otherwise stated, the α level was set at 0.01.

Results

Descriptive profiles

Not surprisingly, all young controls reported to perceive all six odorants and thus had little difficulty in assigning verbal labels to the stimuli. With only few exceptions (seven with menthol and three with propanol), all elderly subjects also reported to perceive all six odorants at the concentrations presented and thus were also able to judge the quality of the stimuli using the list of descriptors.

Figure 2 shows the descriptive profiles derived from the adjectives assigned to each odorant by the control group. The young subjects judged menthol and cineole as distinctly cool and fresh, with >50% of subjects assigning these

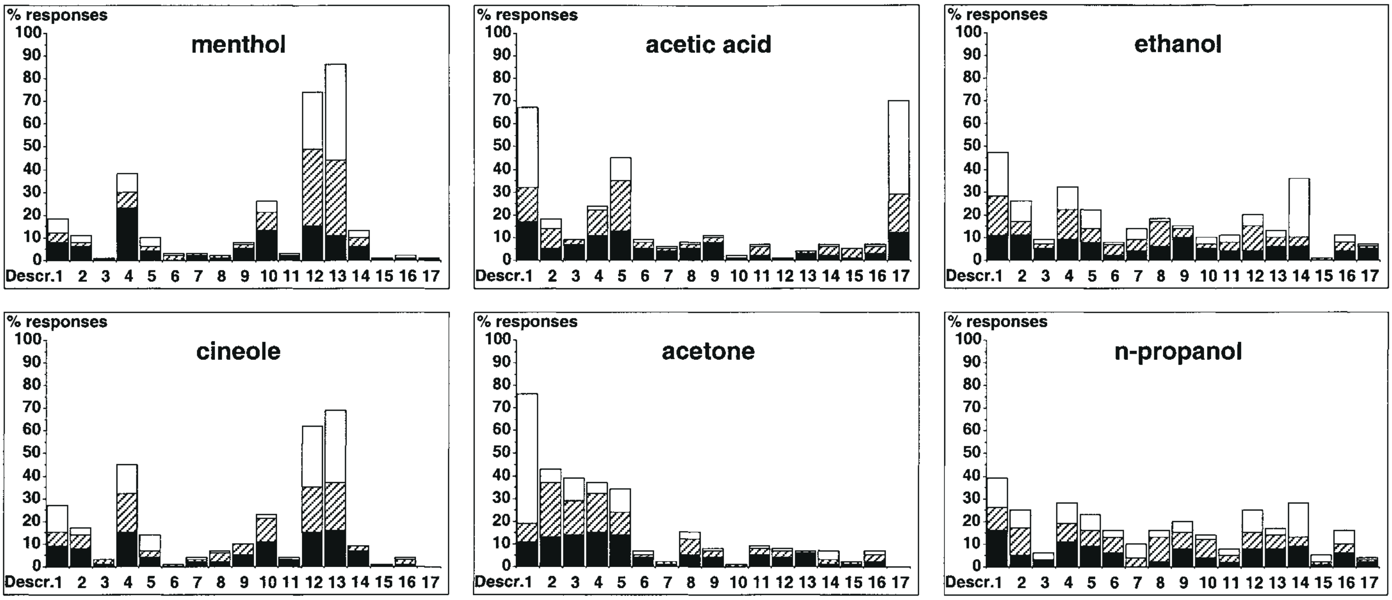

Figure 2 Descriptive profiles derived from the six-item test of odour labelling in which young control subjects ($n = 100$) were asked to choose the three adjectives best describing each odorant from a list of 17 trigeminal type descriptors. Shown are the percentages of subjects assigning particular adjectives as the first (white), second (shaded) or third choice (black). Descriptor numbers correspond to those in Table 2.

descriptors to both odorants. Using the same criterion acetic acid was labelled as pungent and sour and acetone as pungent. In contrast, judgements for ethanol and propanol were widely scattered with no clear preference shown for any descriptor. The descriptive profiles given by male and female control subjects did not differ significantly from each other for any of the six odorants (Spearman $r_s < 0.26$, $P > 0.05$). Similarly, the descriptive profiles given by smokers and non-smokers did not differ significantly from each other for any odorant (Spearman $r_s < 0.24$, $P > 0.05$).

Table 3 summarizes the Spearman rank correlation coefficients as a measure of similarity between the descriptive profiles given by the control group. Not surprisingly, the profiles for menthol and cineole, which had both been judged as cool and fresh, correlated significantly (Spearman r_s, $P < 0.001$). Similarly, the qualitative judgements for ethanol and propanol, which both lacked clear-cut profiles, correlated significantly (Spearman r_s, $P < 0.001$).

The verbal labels assigned to ethanol and propanol also correlated significantly, although to a lesser degree, with those assigned to menthol, cineole and acetone. The descriptive profile for acetic acid did not correlate significantly with any of the other five odorants, although its correlation with acetone fell short of statistical significance (Spearman r_s, $P < 0.06$) and clearly reached statistical significance when the label 'sour' was removed from the calculations (Spearman $r_s = 0.77$, $P < 0.01$).

Figure 3 shows the descriptive profiles derived from the verbal labels assigned to each odorant by the group of elderly subjects. In accordance with the control group, >50% of the elderly subjects judged menthol as distinctly cool and fresh, acetic acid as sour (but, in contrast to the controls, not as pungent) and acetone as pungent. Also in agreement with the control group, the descriptive profiles for ethanol and propanol were widely scattered with no clear preference shown for any descriptor. In contrast to the young controls, the elderly did not judge cineole as distinctly cool and fresh, but as sharp.

The descriptive profiles given by male and female elderly did not differ significantly from each other for any of the six odorants (Spearman $r_s < 0.23$, $P > 0.05$). Similarly, the descriptive profiles given by smokers and non-smokers among the elderly did not differ significantly from each other for any of the six odorants (Spearman $r_s < 0.20$, $P > 0.05$).

Table 3 Correlations[a] between the descriptive profiles given by the control subjects

	Cineole	Acetic acid	Acetone	Ethanol	Propanol
Menthol	0.93[b]	–0.21[c]	0.21[c]	0.63[d]	0.77[e]
Cineole		–0.16[c]	0.39[c]	0.72[e]	0.79[e]
Acetic acid			0.47[c]	0.29[c]	0.18[c]
Acetone				0.67[e]	0.57[e]
Ethanol					0.90[b]

[a]Spearman rank correlation coefficients r_s are given.

[b]$P < 0.001$.

[c]Not significant.

[d]$P < 0.05$.

[e]$P < 0.01$.

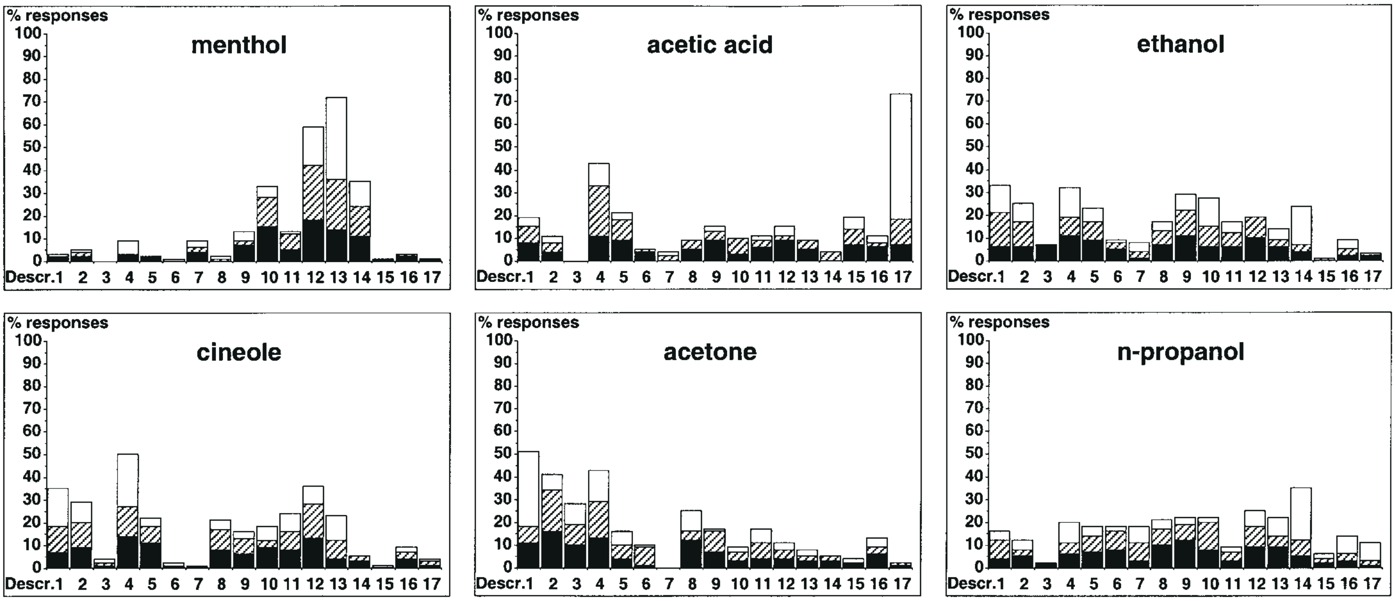

Figure 3 Descriptive profiles derived from the six-item test of odour labelling in which elderly subjects ($n = 100$) were asked to choose the three adjectives best describing each odorant from a list of 17 trigeminal type descriptors. Shown are the percentages of subjects assigning particular adjectives as the first (white), second (shaded) or third choice (black). Descriptor numbers correspond to those in Table 2.

A split of the group of elderly subjects into age classes of 5 years each (65–69 years, 70–74 years, etc.) did not reveal any significant age-related changes in the descriptive profiles for any of the six odorants as the corresponding profiles for a given odorant correlated significantly with each other (Spearman $r_s > 0.58$, $P < 0.01$). Similarly, a split of the group of elderly subjects at the median of the age distribution into two sub-groups of younger elderly (65–74 years, $n = 54$) and older elderly (75–88 years, $n = 46$) did not reveal any significant age-related differences in the descriptive profiles for any of the six odorants as here too the profiles for a given odorant correlated significantly with each other (Spearman $r_s > 0.75$, $P < 0.001$).

Table 4 summarizes the Spearman rank correlation coefficients as a measure of similarity between the descriptive profiles given by the group of elderly subjects. In agreement with the control group, the profiles for menthol and cineole and those for ethanol and propanol correlated significantly (Spearman r_s, $P < 0.05$). Also in line with the young controls, the verbal labels assigned to ethanol correlated significantly with those assigned to menthol, cineole and acetone (Spearman r_s, $P < 0.05$) and the descriptive profile for acetic acid did not correlate significantly with any of the other five odorants (Spearman r_s, $P > 0.05$). Altogether, the occurrence or lack of significant correlations between the descriptive profiles of the six odorants corresponded in 12 of 15 cases between elderly subjects and young controls (cf. Tables 3 and 4).

Table 5 shows the Spearman rank correlation coefficients as a measure of similarity between the descriptive profiles given by the elderly subjects and those given by the young controls. For all six odorants the judgements of the two groups correlated significantly with each other (Spearman r_s, $P < 0.05$) and with the exception of acetic acid and propanol this correlation was even significant at the 1% level of significance.

Table 4 Correlations[a] between the descriptive profiles given by the elderly subjects

	Cineole	Acetic acid	Acetone	Ethanol	Propanol
Menthol	0.54[b]	–0.12[c]	–0.12[c]	0.50[b]	0.73[d]
Cineole		0.40[c]	0.66[d]	0.74[d]	0.28[c]
Acetic acid			0.18[c]	0.27[c]	–0.15[c]
Acetone				0.59[b]	–0.15[c]
Ethanol					0.50[b]

[a]Spearman rank correlation coefficients r_s are given.

[b]$P < 0.05$.

[c]Not significant.

[d]$P < 0.01$.

Discrimination

Figure 4 summarizes the performance of both the young controls and the elderly subjects when asked to compare three sniff bottles and identify the odd stimulus. The control group performed significantly above chance level in all nine discriminations (binomial test, $P < 0.01$). However, significant differences in performance were found between

Table 5 Correlations[a] between the descriptive profiles given by the young controls and the elderly subjects

Odour	r_s	P
Menthol	0.79	0.0015
Cineole	0.81	0.0011
Acetic acid	0.49	0.0482
Acetone	0.92	0.0002
Ethanol	0.77	0.0022
Propanol	0.56	0.0245

[a]Spearman rank correlation coefficients r_s are given.

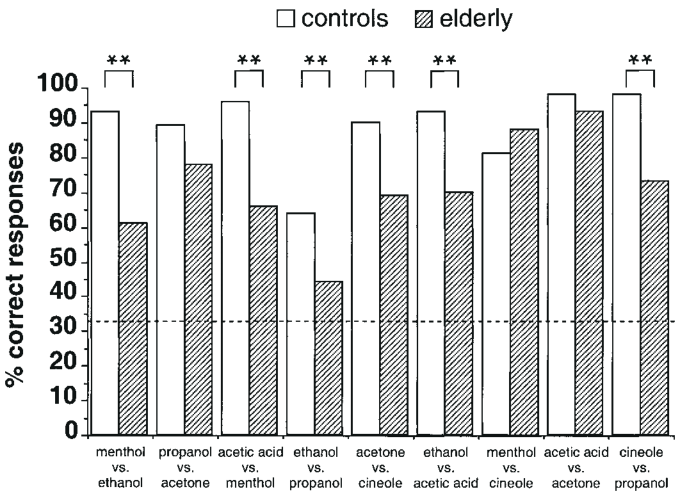

Figure 4 Performance of young controls and elderly subjects in the nine-item discrimination test in which subjects were required to compare three sniff bottles and identify the odd stimulus. Given are percentages of correct responses per group. The dotted line represents the chance level of performance (**$P < 0.01$, χ^2).

tasks and one stimulus pair (ethanol versus propanol) was significantly more difficult to discriminate for the controls than all other tasks (χ^2, $P < 0.01$). The two stimulus pairs resulting in the lowest number of correct responses in the control group (ethanol versus propanol and menthol versus cineole) showed the highest degree of correlation in the descriptive profiles of their constituent odorants and in three of the six tasks in which the controls scored >90% correct decisions (acetic acid versus menthol, acetone versus cineole and ethanol versus acetic acid) the profiles of the constituent odorants did not correlate with each other at a significant level (Table 3). Thus, a negative correlation between discrimination performance (Figure 4) and similarity of odorants in terms of correlation coefficients (Table 3) was found that fell short of statistical significance (Spearman $r_s = -0.46$, $P > 0.05$) as there were also odour pairs which were easily discriminated despite significant correlations in their descriptive profiles.

The group of elderly subjects discriminated 8 of 9 stimulus pairs at the 1% level of significance and the remaining pair (ethanol versus propanol) still significantly above chance (binomial test, $P < 0.05$). Similar to the young controls, significant differences in performance were found between tasks and ethanol versus propanol, i.e. the same stimulus pair as with the control group, was significantly more difficult to discriminate for the elderly than all other tasks (χ^2, $P < 0.01$). Thus here too a negative correlation between discrimination performance (Figure 4) and similarity of odorants in terms of correlation coefficients (Table 4) was found that fell short of statistical significance (Spearman $r_s = -0.43$, $P > 0.05$) due to stimulus pairs that were readily discriminated by the elderly despite significant correlations in their descriptive profiles.

Correlational analyses revealed that there was no significant age-related decline in discrimination performance within the group of elderly subjects (Spearman $r_s = 0.12$, $P > 0.05$). A split of the group of elderly subjects at the median of the age distribution into two sub-groups of younger elderly (65–74 years, $n = 54$) and older elderly (75–88 years, $n = 46$), also failed to show significant age-related differences as the former performed only slightly better than the latter, with an average 6.5 and 6.3 of 9 decisions correct, respectively (Mann–Whitney *U*-test, $P > 0.05$).

Statistical analyses also failed to find significant correlations between discrimination performance and use of medication (Spearman $r_s = 0.15$, $P > 0.05$), smoking habit, (Spearman $r_s = 0.18$, $P > 0.05$) and MMST scores (Spearman $r_s = 0.08$, $P > 0.05$), respectively, among the elderly.

A comparison of the discrimination performance between young controls and elderly subjects showed that the former scored significantly better than the latter in all tasks but three (χ^2, $P < 0.01$; Figure 4). The across-task patterns of performance were similar between groups, with both young controls and elderly subjects scoring best with acetic acid versus acetone and poorest with ethanol versus propanol.

Table 6 shows the percentage of judgements reported to be based mainly on differences in perceived stimulus intensity rather than stimulus quality in the nine discriminations. With the exception of two items (menthol versus cineole and ethanol versus propanol), <13% of all decisions made by the young controls were reportedly based on differences in stimulus intensity. These two items were those with the highest correlations in their descriptive profiles and the lowest scores of correct responses for this group (cf. Table 3 and Figure 4).

In the group of elderly subjects the percentage of judgements reported to be based on differences in perceived intensity rather than quality was significantly higher compared with the controls in all nine tasks (χ^2, $P < 0.05$). However, the across-task patterns of this measure correlated signficantly between groups (Spearman $r_s = 0.70$, $P < 0.05$) and in both the young controls and the elderly subjects a significant negative correlation between the frequency of

Table 6 Percentage of judgements reported to be based mainly on differences in perceived stimulus intensity rather than stimulus quality

Odour pair	Elderly	Controls
Menthol versus ethanol	53	7
Propanol versus acetone	29	12
Acetic acid versus menthol	43	4
Ethanol versus propanol	61	27
Acetone versus cineole	27	4
Ethanol versus acetic acid	28	0
Menthol versus cineole	45	30
Acetic acid versus acetone	20	4
Cineole versus propanol	35	5

naming differences in stimulus intensity as choice criterion and the percentage of correct decisions was found (Spearman $r_s = -0.66$, $P < 0.02$ for the young controls and Spearman $r_s = -0.60$, $P < 0.03$ for the elderly subjects).

Discussion

Two main findings emerge from the present study.

1. The descriptive profiles given by elderly subjects in response to odorants known to have a strong trigeminal component correlated significantly with those given by young controls and thus indicate a high degree of conformity in trigeminal perception of chemosensory quality between the two age groups.
2. The overall discrimination performance of the elderly subjects was significantly poorer than that of the young controls but nevertheless significantly above chance at the group level with all stimulus pairs tested. This suggests that the nasal trigeminal system may experience some degree of age-related impairment but still contributes considerably to chemosensory quality discrimination.

The results obtained with the young controls in the first part of the study are in full agreement with those of an earlier study (Laska *et al.*, 1997) which employed exactly the same odorants and paradigm with a smaller sample of exclusively male subjects. In both studies young normosmic subjects clearly judged menthol and cineole as cool and fresh, acetic acid as pungent and sour, acetone as pungent and showed no clear descriptive profile for ethanol and propanol, thus confirming this finding to be robust. The fact that congenitally anosmic subjects assigned exactly the same labels to these odorants (with the exception of sour for acetic acid) strongly suggests that these sensations are indeed likely to be mediated by the nasal trigeminal system (Laska *et al.*, 1997) and thus lend support to von Skramlik's claim that particular odorants possess distinct trigeminal qualities (von Skramlik, 1926).

The present finding that the descriptive profiles given by the elderly subjects correlated significantly with and thus were quite similar to those given by the young controls (and to those given by the anosmic subjects tested in the earlier study) for all six odorants indicates that the ability of the nasal trigeminal system to perceive volatile chemical stimuli and even identify distinct qualities of such stimuli shows only little age-related change. This is consistent with the idea that the primary function of the nasal trigeminal system is to protect the organism from potentially harmful or noxious chemicals (Silver, 1987), i.e. a function that clearly remains important across the whole lifespan.

The finding of a largely preserved ability of elderly subjects to perceive chemosensory stimuli via their fifth cranial nerve is also in line with earlier reports of either no (Stevens and Cain, 1986) or only little (Wysocki *et al.*, 1997) age-related impairment in nasal trigeminal sensitivity, although it is important to note that the same study that found no differences in nasal trigeminal detection thresholds between young and elderly subjects also reported responses to suprathreshold concentrations of CO_2 to markedly decrease with age (Stevens and Cain, 1986).

Similarly, Polich *et al.* reported a lack of age effects on both latencies and amplitudes of evoked potentials in response to mild electrical stimulation of the human lower lip (Polich *et al.*, 1995), which suggests that the trigeminal system *in toto* may be quite resistant to age-related impairment.

In the second part of the study young control subjects were clearly able to discriminate between odorants known to have a strong trigeminal component. Here again, the results fully agree with those of an earlier study (Laska *et al.*, 1997) which employed the same stimulus pairs with a smaller sample of male subjects. The finding of a negative correlation between discrimination performance and similarity of odorants in terms of correlation coefficients calculated from a comparison of the descriptive profiles obtained in the first part of the study (cf. Tables 3 and 4) suggests that the nasal trigeminal system at least contributed to the discrimination of the stimuli. This supposition is supported by earlier findings which reported congenitally anosmic subjects to perform only slightly poorer in this task compared with normosmic controls (Laska *et al.*, 1997).

The finding that the group of elderly subjects was also able to distinguish between all 9 stimulus pairs, although generally with lesser accuracy than the young controls (Figure 4), is remarkable given the dramatic decline in olfactory recognition and discrimination performance with age reported in several studies that employed odorants with no or only little trigeminal-stimulating properties (Weiffenbach, 1991; Schiffman, 1997; Lehrner *et al.*, 1999). As the stimuli employed here elicit sensations mediated both by the olfactory and the nasal trigeminal systems the question arises as to whether the relatively good performance of the elderly subjects in the discrimination task was at least partially based on their ability to perceive and make use of different trigeminal qualities. The existence of at least two distinct trigeminal qualities, namely 'cool-fresh' and 'pungent', is supported by the results of the first part of the present study (cf. Figures 2 and 3), as well as by results of an earlier study that employed the same odorants with anosmic subjects (Laska *et al.*, 1997) and by findings from other authors which have shown that these sensations are likely to be mediated by two different fiber systems, i.e. unmyelinated C fibres and myelinated A_δ fibres, of the trigeminal nerve (Sekizawa and Tsubone, 1994; Hummel, 2000). In line with the young controls, the discrimination performance of the elderly subjects correlated negatively with qualitative similarity of odorants as obtained from a comparison of the trigeminal type descriptive profiles (cf. Figure 3 and Table 4). This suggests that, here too, the nasal trigeminal system at least contributed to discrimination of the stimuli.

Other findings, however, indicate that the olfactory system was also involved in the judgement and discrimination of stimuli. In contrast to anosmic subjects (Laska *et al.*, 1997), for example, both young and elderly subjects described acetic acid as sour (cf. Figures 2 and 3), which thus is unlikely to be a sensation evoked by trigeminal stimulation. A more likely explanation for the frequently reported phenomenon of odorants being constantly described as possessing a taste-related quality (Rozin, 1982) is that associative mechanisms may underlie the development of taste–smell confusions. This hypothesis is supported by findings from Stevenson *et al.*, who plausibly argue that the acquisition of taste properties by odors may result from the co-occurrence of certain odors and tastes outside the laboratory (Stevenson *et al.*, 1999).

Alternatively, the possibility that the concentration of acetic acid employed here was sufficiently high to reach the oral cavity retronasally and elicit neural responses in sour taste receptors cannot be excluded. This hypothesis, however, is not supported by findings from an earlier study, which reported only 1 of 20 congenitally anosmic, but presumably eugeusic, subjects to assign the label sour to the same concentration of acetic acid as employed here (Laska *et al.*, 1997).

The finding that in both young controls and elderly subjects the descriptive profiles for acetic acid did not correlate with any of the other odorants (cf. Tables 3 and 4) but that they did correlate with those for acetone and ethanol when the descriptor sour is removed from the calculations shows that the olfactory system also contributed to the quality perception and discrimination of stimuli and illustrates the dual property of acetic acid as a (pungent) trigeminal and (sour) olfactory/taste stimulus.

The lack of a significant correlation between discrimination performance and age within the group of elderly subjects and the remarkable correspondence between young controls and elderly subjects in the use of trigeminal type descriptors to judge the odorants presented here suggest that the poorer discrimination performance of the elderly may be attributed to losses in olfactory rather than trigeminal capabilities.

An alternative explanation for the relatively good performance of the elderly subjects in distinguishing between odorants found in the present study is that despite efforts to present stimuli in intensity-matched concentrations, discrimination might have been based on the ability of subjects to perceive and make use of subtle differences in stimulus intensity rather than stimulus quality. Although this possibility cannot be ruled out completely, it seems unlikely as a significant negative correlation between the frequency of naming differences in stimulus intensity as choice criterion and the percentage of correct decisions was found in both young controls and elderly subjects. Thus, the instances in which perceived differences in stimulus intensity were reported seem to mirror a subject's difficulty to discriminate at all. This supposition is also supported by corresponding findings from other studies that employed the same discrimination paradigm with different sets of stimuli (Laska and Teubner, 1999a,b; Laska *et al.*, 2000; Laska and Hübener, 2001).

A final aspect of the present study is the potential real life relevance of the findings.

Elderly are at a considerably increased risk of suffering from gas poisoning (Stevens and Cain, 1987). Given the well-documented decline in olfactory performance with age (Lehrner *et al.*, 1999), the present findings suggest that warning agents added to household gas should not only be malodorous, as usually is the case, but also have a strong trigeminal component in order to increase the chances of the elderly perceiving and identifying its presence.

Age-related impairment of smell function has also been shown to decrease enjoyment of food and thus to increase the risk of malnutrition (Schiffman and Warwick, 1991). The present findings make it seem worthwhile to elucidate whether adding chemosensory food enhancers with a trigeminal component could be used as a means to restore enjoyment of food and thus to promote acceptance and consumption of a balanced diet.

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