Chem. Senses 24: 337–346, 1999

Odor Identification, Consistency of Label Use, Olfactory Threshold and their Relationships to Odor Memory over the Human Lifespan

Johann P. Lehrner, Judith Glück[1] and Matthias Laska[2]

Neurologische Universitätsklinik and [1]Abteilung für Entwicklungspsychologie, Institut für Psychologie, Universität Wien, Wien, Austria and [2]Institut für Medizinische Psychologie, Ludwig-Maximilian-Universität München, München, Germany

Mag. Johann Lehrner, Neurologische Universitätsklinik, Allgemeines Krankenhaus, Währingergürtel 18–20, A-1097 Wien, Austria. e-mail: hannes.lehrner@akh-wien.ac.at

Abstract

The purpose of this study was to investigate olfactory threshold, odor identification, consistency of label use and their relationships to odor memory in the context of semantic/episodic memory across the human lifespan. A total of 137 subjects aged 4–90 years were tested with several olfactory test procedures. We found that olfactory sensitivity was well developed in children despite the finding that their odor naming and odor memory were inferior to that of adults. In the elderly population, olfactory functions gradually declined, with odor memory and odor identification demonstrating the most significant decline. Semantic encoding was differentially related to odor memory over the human age span. Whereas consistency of label use was the main predictor for odor memory in children and young adults, olfactory identification ability was the main predictor in the elderly study group. We also calculated response bias for the separate age groups and found no differences between children, young adults and elderly. However, with age false alarm rates increased. We conclude that children possess equal olfactory sensitivity compared with adults; however, due to limitations in linguistic capabilities and familiarity to odorants, odor memory and odor identification performance was limited. Additionally, our data indicate major alterations of olfactory processing in advanced age with substantial losses in odor memory and odor identification performance.

Introduction

Recent reports studying olfaction in children revealed that olfactory threshold is no different between children and young adults (Koelaga and Köster, 1974; Perry *et al.*, 1980; Cain *et al.*, 1988, 1995; Dorries *et al.*, 1989; Solbu *et al.*, 1989). However, olfactory identification performance was found to be poorer in children than in young adults (Doty *et al.*, 1985; Rothschild *et al.*, 1995), showing that processes different from olfactory sensitivity may be responsible for improved odor identification with increasing age (Richman *et al.*, 1995).

As with other sensory modalities, olfactory capabilities are negatively correlated with age in adults. The elderly experience a decrease in olfactory sensitivity and a loss of suprathreshold odor intensity perception as measured by magnitude matching methods. Additionally, odor classification, odor discrimination, odor identification ability and odor memory are impaired as well (Schiffman *et al.*, 1976; Schiffman and Pasternak, 1979; Schemper *et al.*, 1981; Doty *et al.*, 1984; Stevens and Cain, 1985, 1987a; Eskenazi *et al.*, 1986; Murphy, 1986; Murphy *et al.*, 1991, 1997; DeWijk and Cain, 1994; Cain *et al.*, 1995). The decrement of olfactory functions has real-world significance when identification of blended food and the usefulness of olfactory warning agents are considered. Both identification of blended foods and detection of mercaptans as warning agents in cooking gas are impaired in the elderly population (Stevens *et al.*, 1987b; Wysocki and Pelchat, 1993).

The underlying mechanism for the observed differences of olfactory capabilites across the human lifespan have not yet been untangled. Whether they are biological in nature, e.g. maturation of cerebral structures in children or loss of cells in the elderly, or of psychological nature, e.g. compromised use of cognitive operations such as active encoding, active retrieval and use of verbal labels by children and the elderly, have not been sufficiently examined. The relationship between odor memory and semantic processing in young adults has been investigated by a number of studies. In general, it has been found that labeling of odors enhances odor memory substantially (Engen and Ross, 1973; Rabin and Cain, 1984; Lyman and Mc Daniel, 1986, 1990; Schab, 1991; Lehrner, 1993; Schab and Crowder, 1995; Herz and Engen, 1996).

In addition, it has been shown that labeling an odor with the same tag at studying and testing has a strong influence on odor recognition memory. That is, consistently labeled odors are much better remembered than inconsistently labeled odors (Rabin and Cain, 1984; Lehrner, 1993). These data suggest that semantic memory processes play an important role in odor memory (Larsson, 1997b). Recent research with elderly study populations suggest that impaired odor memory is largely attributable to cognitive factors such as odor naming. Larsson and Bäckman (1993) documented that access to verbal labels largely determined age differences in recognition of common odors. Additionally, Murphy *et al.* (1991, 1997) reported significantly impaired odor memory and olfactory identification performance in elderly when compared with young adults. They suggested that cognitive factors such as encoding, storing and retrieving appear to predict odor memory. For children, however, there is a lack of data regarding the importance of semantic factors in odor memory.

In recognition memory experiments, hit rates and false alarm rates are important parameters and are used to compute discrimination indices and response bias measures. Such measures are age related and they have been linked to encoding of to-be-remembered items. Studies with non-olfactory stimuli showed age-related increases of false alarm rates in the elderly for faces (Ferris *et al.*, 1980; Bartlett and Leslie, 1986; Bartlett *et al.*, 1989). Increased false alarm rates in the elderly have been related more to a reliance on perceived familiarity and less on conscious recollection in making recognition judgements relative to the young (Bartlett *et al.*, 1991).The issue of age-related increases in false alarm errors has not been sufficiently investigated for olfactory stimuli. False alarm errors are worthwhile to investigate for the olfactory modality because considerably higher false alarm rates for olfactory stimuli compared with visual or auditory stimuli can be expected (Engen, 1982). Two studies reported increased false alarm rates for the elderly compared with young adults in an olfactory recognition paradigm (Larsson and Bäckman, 1993; Murphy *et al.*, 1997). However, to our knowledge no data for children are available.

The purpose of this investigation was to assess, for the first time, odor recognition memory performance, odor identification, consistency of label use and olfactory threshold in a sample of subjects across the human lifespan. We performed this investigation in order to gather new information regarding these olfactory functions across different developmental stages. Based on the literature review, we expected a negative correlation between age and olfactory sensitivity, and an inverse U-shaped function for odor naming and memory. Another goal of this study was to address, for the first time, the relationships of olfactory sensitivity and odor naming to odor memory performance across the human life range. We hypothesized that verbal naming, i.e. semantic encoding, contributes to odor memory over the human age range, but that, specifically in elders, sensory factors such as detection threshold determines odor memory performance. In addition, we investigated whether hit rates and false alarm rates are age-related.

Materials and methods

Subjects

A total of 142 subjects took part in the experiment. Olfactory data of 137 subjects (51 males and 86 females) were eventually used in the statistical analyses because six subjects left the experiment without completing it. Subjects were split into four age groups: children from 4 to 11 years (age group 1; $n = 42$), young adults from 18 to 30 years (age group 2; $n = 55$), middle-aged adults from 31 to 57 years (age group 3; $n = 22$), and elderly subjects with an age range from 64 to 90 years (age group 4; $n = 18$). The children were from a Vienna Elementary School and the young subjects were mostly students of the University of Vienna. Elderly people were independently living senior citizens of Vienna. For demographic characteristics of the subject groups see Table 1.

Method

The test battery consisted of an odor detection threshold task, an odor identification task (everyday odors are to be identified) and an odor recognition memory task (retention time 15 min). For the olfactory identification task and odor memory task, 20 odorants were used. All were chosen to be readily identifiable and are frequently used in the common household. The odorants were as follows: peppermint, aniseed, juicy-fruit chewing gum, turpentine, cloves, cinnamon, cocoa, coffee, mustard, cigarette butts, lemon, orange, shower gel, brandy, almond oil, garlic, dried coconut, soap, gasoline, Nivea (skin cream). A very similar testing procedure was used for assessing HIV-infected individuals, and patients with Alzheimer's disease and Parkinson's disease (Lehrner *et al.*, 1995, 1997), and the same procedural rules were applied in the present study. The test took ~30 min.

Odor recognition memory and olfactory identification

Subjects smelled in succession 10 odorants out of the 20 item odor pool. A stimulus presentation rate of 30 s was used in order to control possible stimulus adaptation effects.

Table 1 Demographic characteristics of subjects groups

	n	Mean age (SD)	Age range	Male/ female	Smoker/ non-smoker
Children	41	8.2 (1.7)	4–11	20/21	0/41
Young adults	56	24.9 (2.7)	18–30	20/36	35/21
Middle-aged adults	22	40.7 (9.1)	31–57	8/14	13/9
Elderly people	18	77.8 (8.2)	64–90	3/15	1/17

While inspecting the odors, the subjects closed their eyes and usually took 1–3 sniffs lasting for ~5 s. The odorants were presented in random order for every subject in glass bottles wrapped with adhesive tape to prevent participants from visually detecting the contents. The subjects were told to name the odor as correctly as possible with one word and to memorize the odor because they would be tested later to see how well they could remember the odors. After a retention interval of 15 min the memory recognition test took place. The odorants were again given every 30 s. For the 20 stimuli, presented in random order, the subjects judged whether the odorant was 'old' (i.e. a target from the inspection set) or 'new'. After deciding this, the subjects named the odorant. Again they were told to use just one word. Olfactory identification ability was regarded to be a direct route to semantic knowledge of subjects about the presented odors.

Consistency of label use

The verbal encoding of the odors was analyzed in terms of consistency of label use. When a person uses the same verbal descriptor both at inspection and testing, very similar verbal encoding can be assumed. However, the use of different labels on the two occasions implies different verbal encoding at inspection and testing (Rabin and Cain, 1984; Lehrner, 1993). On the basis of this scoring, it was possible to learn more about subjects' usage of semantic encoding according to their consistency of label use. Consistency of label use was thus seen as an overt measure of the usage of semantic information.

Olfactory detection threshold

Odor threshold testing was established by using a 1-butanol ascending staircase, two-bottle, forced-choice method (Cain *et al.*, 1988). Beginning at the lowest concentration, subjects received a serial dilution set of 1-butanol beginning at 4% in distilled water and progressing in 10 steps of successive thirds (dilution factor 3) and a water control. On a given trail subjects sniffed consecutively from two amber glass bottles and their task was to indicate which bottle contained the butanol solution or smelled stronger. If the subject was incorrect at one concentration, the next higher concentration was presented. Threshold was defined as the butanol concentration correctly chosen over water in four consecutive trails. The corresponding number of the concentration was taken as the threshold value; a high corresponding number represents a low threshold.

Results

First we wanted to answer the question of whether age has an influence on olfactory measures. All dependent variables were tested for differences between any of the four age groups using one-way analysis of variance (ANOVA). For significant results, Scheffe *post hoc* tests were used to search for reliable group differences. Figure 1 illustrates the results.

Odor memory

On the basis of signal detection theory a hit rate and a false alarm rate were derived. Using a technique described by Snodgrass and Corwin (1988), the recognition memory index *Pr* was calculated. Perfect performance is rated as1.0, and 0.0 is performance at random. For the memory measure *Pr*, an ANOVA yielded significant differences [$F(3,133) = 19.52$, $P < 0.001$]. Scheffe *post hoc* tests produced significant differences between the elderly and all other groups (elderly versus children, $P < 0.001$; elderly versus young adults, $P < 0.001$; elderly versus middle-aged adults, $P < 0.001$). Children had significant lower scores than young adults ($P < 0.02$). Young adults and middle-aged adults did not differ ($P > 0.3$), nor did children and middle-aged adults ($P > 0.8$).

Hit rates

The ANOVA on the hit rate data revealed an effect of age, [$F(3,133) = 4.28$, $P < 0.01$]. *Post hoc* Scheffe tests showed that hit rate was significantly higher for young adults compared with the elderly ($P < 0.03$). No other differences were statistically significant (all P values >0.15).

False alarm rates

New odors incorrectly recognized as old were scored as false alarms. The ANOVA on the number of false alarms yielded an effect of age [$F(3,133) = 20.46$, $P < 0.001$]. Scheffe *post hoc* testing revealed that the elderly produced a higher false alarm rate than all other groups (elderly versus children, $P < 0.001$; elderly versus young adults, $P < 0.001$; elderly versus middle-aged adults, $P < 0.001$). No other differences were significant (all P values >0.15).

Response criterion

For the measure of the response criterion we used the bias index (*Br*) suggested by Snodgrass and Corwin (1988). Accordingly, we corrected hit and false alarm rates by adding 0.5 to each frequency and divided by $n + 1$, where n is the number of old or new trials. For the computation of *Br* the transformed values were used. A value of *Br* of 0.5 indicates neutral bias, a value >0.5 indicates liberal bias and a value <0.5 indicates conservative bias. The ANOVA on *Br* data revealed a significant age effect [$F(3,133) = 3.60$, $P < 0.02$]. *Post hoc* Scheffe tests showed that the elderly had a significantly higher *Br* score than middle-aged adults ($P < 0.02$). No other pairwise comparisons were significant (all P values >0.2).

Olfactory identification

Odor identification scores were derived from the naming of the 20 odors at odor memory testing. The word given for identification was scored for correctness. The response to

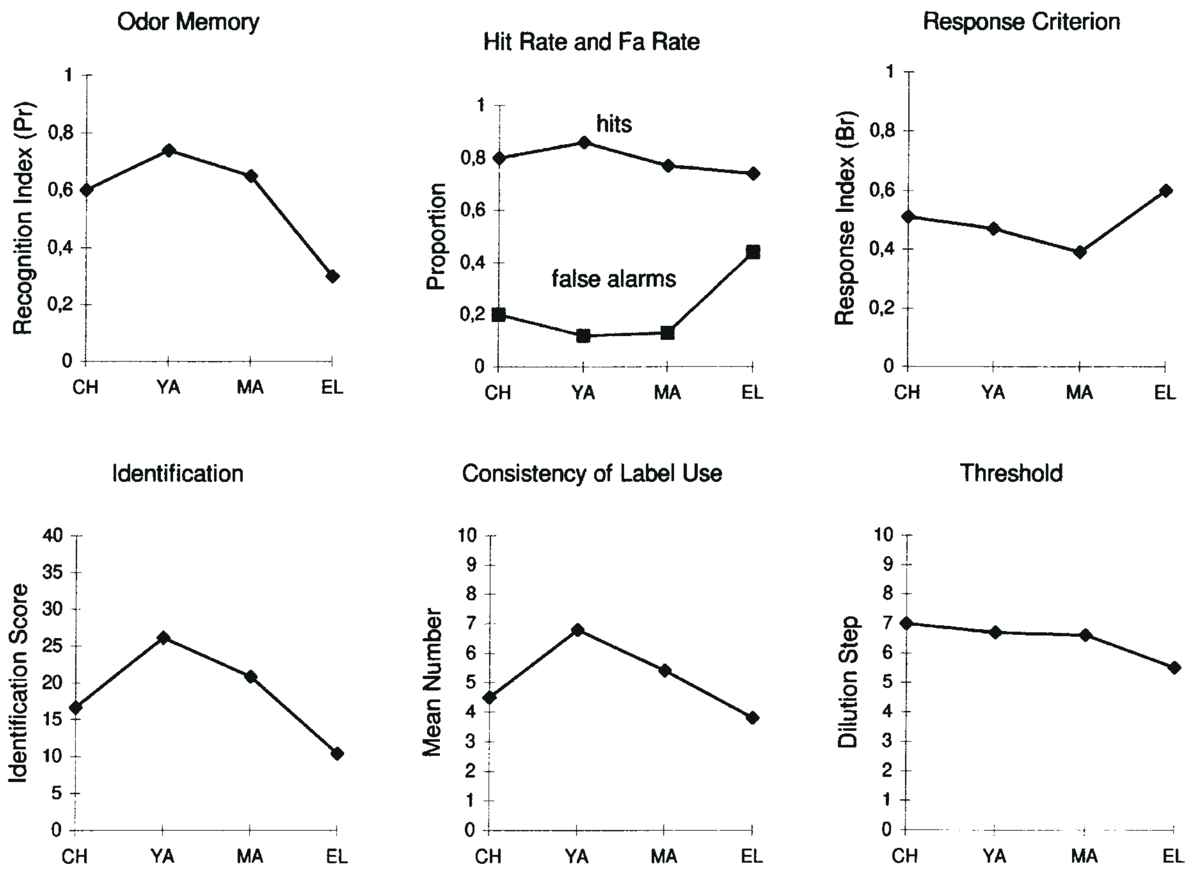

Figure 1 Mean olfactory performance across human age range (CH = children, YA = young adults, MA = middle-aged adults, EL = elderly).

each stimulus was categorized into three levels of correctness using the scheme described by Cain (1979). He categorized the generated odor labels of his subjects into three groups: a veridical label (the true name of the odorant, e.g. gasoline for gasoline; coffee for coffee); a near miss, i.e. names reasonably close to the veridical name (e.g. cinnamon for cloves); and a far miss, i.e. names quite far from veridical labels (e.g. lemon for coffee). Veridical name, near miss and far miss were designated scores of 2, 1 and 0 respectively. A subject could score at most 40 points for the identification of the 20 odors.

Olfactory identification showed a significant age effect [$F(3,133) = 37.8$ $P < 0.001$] and single Scheffe *post hoc* comparisons were significant between young adults and all other groups (young adults versus children, $P < 0.001$; young adults versus middle-aged adults, $P < 0.01$; young adults versus elderly, $P < 0.001$). Additionally, children and middle-aged adults scored significantly better than the elderly (children versus elderly, $P < 0.001$; middle-aged adults versus elderly, $P < 0.007$). Children and middle aged adults did not differ ($P > 0.08$).

Consistency of label use

Subjects were scored on how consistently they used their generated odor label. When a person labeled an odor with the same tag at presentation and testing (e.g. coffee–coffee), same association (SA) was scored. Different association (DA) was scored when a subject labeled an odor differently at initial presentation and testing (e.g. coffee–chocolate). No association (NA) was scored when a subject was not able to generate a label for the odor at presentation and testing, or when a subject could generate only one label either at presentation or at testing. DA and NA scores were pooled. This is a modified version of our previously used categorization method (Lehrner, 1993). The number of consistently labeled odors had an overall age effect [$F(3,133) = 7.5$, $P < 0.001$]. *Post hoc* Scheffe analyses showed significant differences between young adults and children ($P < 0.003$), and between young adults and the elderly ($P < 0.003$). Further pairwise comparisons revealed that young adults versus the middle-aged adults, middle-aged adults versus children and children versus the elderly all did not differ (all P values > 0.30).

Olfactory threshold

The comparison of olfactory threshold across age groups did not reveal a statistical difference. However, a trend was present [$F(3,127) = 2.5$, $P < 0.06$].

Scheffe pairwise comparisons showed a trend only for

Table 2 Mean olfactory performance for split subgroups of young children/older children and young elderly/older elderly

	Odor memory		Hit rate		False alarm rate		Response criterion		Consistency of label use		Identification		Threshold	
	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD
Young children	0.56	0.25	0.78	0.16	0.21	0.17	0.49	0.23	4.2	2.0	15.5	5.5	6.9	2.1
Older children	0.63	0.23	0.82	0.16	0.19	0.14	0.53	0.22	4.9	2.2	17.7	5.1	7.1	1.6
Young elderly	0.40	0.20	0.69*	0.15	0.29*	0.18	0.46*	0.19	2.7	2.1	11.1	4.3	6.5*	1.8
Older elderly	0.20	0.27	0.80	0.20	0.60	0.23	0.73	0.16	4.9	8.6	9.7	5.5	4.5	1.8

*$P < 0.05$, Mann–Whitney *U*-test.

children versus elderly ($P < 0.06$). All other comparisons were not significant (all *P* values >0.16).

Within-group variability

In order to investigate whether there were differences in olfactory performance within the group of children we calculated the age median of children (median = 9 years) and then split the sample into two halves (young children: $n = 20$, mean age 6.8 ± 1.2; older children: $n = 21$, mean age = 9.6 ± 0.7 years). Subsequently we performed separate Mann–Whitney *U*-tests for the variables of odor memory, hit rate, false alarm rate, response criterion, olfactory identification, consistency of label use and olfactory threshold for the two independent samples. Statistical analysis revealed no significant effect of age group on any variable (all *P* values >0.3).

In addition, the elderly population was split along the age median (median = 78) with corresponding two groups (young elderly: $n = 9$, mean age 70.8 years and older elderly: $n = 9$, mean age 84.8 years, respectively). Subsequent separate Mann–Whitney *U*-tests for the variables of odor memory, hit rate, false alarm rate, response criterion, olfactory identification, consistency of label use and olfactory threshold were performed. Mann–Whitney *U*-tests revealed significant differences for the variables of hit rate ($U = 18.5$; $P < 0.05$), false alarm rate ($U = 12.5$; $P < 0.02$), response criterion ($U = 13.0$; $P < 0.02$) and olfactory threshold ($U = 11.0$; $P < 0.03$), whereas odor memory, consistency of label use and olfactory identification showed no significant differences between young elderly and old elderly (Mann–Whitney *U*-tests; all *P* values >0.10). Table 2 shows the results.

Analysis of predictors of odor memory performance

One special interest of this study was to investigate the potential influence of verbal identification, consistency of label use and olfactory threshold on odor memory across the human lifespan. This was done to untangle sensory influences, e.g. olfactory threshold, from more cognitively influenced measures such as odor identification and consistency of label use. In order to investigate this issue, we calculated analyses of covariance (ANCOVA) with olfactory threshold, odor identification and consistency of label use as covariates. ANCOVA compares group means after adjusting those means for a third variable, or covariate. If differences in group means could be explained based on the relationship with the third variable, results from the ANCOVA would not be statistically significant. Controlling for olfactory threshold, odor identification and consistency of label use with separate ANCOVAs did not change results. When adjusting for all three covariates, significant age differences for *Pr* were still apparent [$F(3,124) = 4.0$, $P < 0.009$].

The ANCOVA does not directly evaluate the strength of association between two variables and is thus not helpful in elucidating the relationship between odor memory and the variables of olfactory threshold, odor identification and consistency of label use. Because of the non-monotonic changes in performance for odor memory, odor identification and consistency of label use across age, we calculated product–moment correlations for the adults groups only, between chronological age, olfactory threshold, odor identification, consistency of label use and odor memory, and we also calculated correlation coefficients for the whole sample. The correlational analyses for adults indicated a significant negative relationship between age and odor identification, odor memory, consistency of label use and olfactory threshold. Olfactory threshold correlated negatively with both odor memory and odor identification. Highly significant positive relationships were found between odor identification, consistency of label use and odor memory performance. Table 3A shows the results. An interesting finding is the significant negative correlation between false alarm rate and olfactory threshold ($r = -0.37$). A closer inspection of the correlations between false alarm rate and threshold in each age group revealed nonsignificant correlations in children ($r = -0.05$), young adults ($r = -0.23$) and middle-aged adults ($r = -0.18$) respectively. However, a significant negative correlation emerged in the elderly age group ($r = -0.53$; $P < 0.05$).

When including children in the analysis, the pattern of

Table 3 Correlations of chronological age, olfactory threshold, odor identification, consistency of label use and odor memory

Variables	1	2	3	4	5	6	7
(A) Adults ($n \geq 94$)							
(1) Chronological age	–						
(2) Threshold	–0.24*	–					
(3) Odor identification	–0.69**	0.31**	–				
(4) Consistency of label use	–0.34**	0.17	0.57**	–			
(5) Odor memory performance	–0.65**	0.31**	0.69**	0.54**	–		
(6) Hit rate	–0.31**	0.06	0.49**	0.51**	0.65**	–	
(7) False alarm rate	0.62**	–0.37**	–0.56**	–0.34**	–0.85**	–0.14	–
(B) Whole sample ($n \geq 131$)							
(1) Chronological age	–						
(2) Threshold	–0.24**	–					
(3) Odor identification	–0.29**	0.18*	–				
(4) Consistency of label use	–0.11	0.10	0.61**	–			
(5) Odor memory performance	–0.39**	0.22*	0.62**	0.51**	–		
(6) Hit rate	–0.15	0.05	0.46**	0.52**	0.69**	–	
(7) False alarm rate	0.42**	–0.26**	–0.48**	–0.28**	–0.80**	–0.13	–

*$P < 0.05$; **$P < 0.01$.

correlations among performance scores remained the same although the correlation coefficients usually decreased slightly. Table 3B shows the results.

In order to analyze the interrelationships between olfactory threshold, odor identification, consistency of label use and odor memory, multiple regression analyses for the whole sample and for each age group separately were calculated. Olfactory threshold, odor identification and consistency of label use were used as predictor variables and *Pr* was the dependent or criterion measure. Data were analyzed by stepwise regression analysis.

Table 4 shows the results of the regression analyses including the standardized beta weights for the significant predictor variables. First we report our results concerning the whole sample. Regression analysis was highly significant ($P < 0.001$), accounting for 42% of the variance. Two variables were powerful predictors, with olfactory identification being highly associated and consistency of label use being moderately associated to odor memory. Olfactory threshold was not a significant predictor and thus was removed from the equation.

Separate multiple regression analyses revealed that in the subsamples of children, young adults and middle-aged adults consistency of label use was the main predictor of odor memory performance. Stepwise regression analysis for the elderly group revealed odor identification as the main predictor. Consistency of label use and olfactory threshold did not reach the significance level of $\alpha = 0.05$ and thus were removed. However, the partial correlation coefficient between odor memory and olfactory threshold ($r_{part} = 0.47$, $P > 0.08$) indicated a statistical trend.

Discussion

The present experiments sought to clarify some questions regarding olfactory functions during the human life cycle and the relationship of odor detection sensitivity and odor naming to odor memory performance. Our investigation confirmed that olfactory sensitivity is well developed in children although odor recognition memory performance and odor naming are somewhat limited. Additionally, we confirmed a marked decline in olfactory functioning for the elderly, which is indicative of alterations in the olfactory system. Semantic encoding is correlated with odor memory to a varying degree over the human lifespan. Whereas in children and young adults, semantic context is the main predictor of odor memory, odor identification ability is the main predictor in the elderly. Deficits for both hits and false alarms in odor recognition were also found in the elderly. Motivational factors, as expressed by response bias parameters, were not different between children, young adults and the elderly study group. Thus, we found converging evidence suggesting major changes in processing of olfactory stimuli across the human age range.

We confirmed that children are as sensitive as young adults for 1-butanol. As age increases, olfactory sensitivity decreases in a monotonic fashion. This is indicated by a negative correlation coefficient and a trend in the ANOVA. Our data are in accordance with previous reports in the literature (Koelega and Köster, 1974; Dorries *et al.*, 1989; Cain *et al.*, 1995).

For the more cognitively demanding tasks of odor memory, consistency of label use and odor identification we obtained clear-cut results. Odor recognition memory, consistency of label use and olfactory identification showed a

Table 4 Results of separate stepwise multiple regression analysis for the whole sample, children, young adults, middle-aged adults and elderly adults

	Test	R^2	P	Significant predictors (beta)
Whole sample (n = 131)	odor memory	0.42	<0.001	odor identification (P < 0.001), β = 0.48 consistency of label use (P < 0.007), β = 0.23
Children (n = 37)	odor memory	0.26	<0.001	consistency of label use (P < 0.001), β = 0.51
Young adults (n = 56)	odor memory	0.44	<0.001	consistency of label use (P < 0.001), β = 0.66
Middle-aged adults (n = 22)	odor memory	0.25	<0.001	consistency of label use (P < 0.001), β = 0.47
Elderly (n = 16)	odor memory	0.42	<0.001	odor identification (P < 0.001), β = 0.65

non-monotonic change with increases from childhood to adulthood and then a decrease throughout adulthood with impaired functioning in the elderly. Our findings confirm previous reports for olfactory identification (Cain *et al.*, 1995) and are novel for odor memory and consistency of label use.

The functional importance of the sense of smell in children has been demonstrated by other investigators as well (Engen, 1986; Schmidt and Beachamp, 1988; Schaal, 1988; Porter, 1991). Regarding the human sense of smell in infants, Sullivan *et al.* (1991) provided the first evidence that infants are capable of olfactory associative learning during the first day after birth. This finding is remarkable because it shows that the infant odor memory system is independent of semantic memory functioning.

Slow acquisition of names for odors has been reported in adults (Davis, 1975, 1977). Recently, Cain *et al.* (1995) provided evidence that children improved faster than adults on explicit paired-associate learning of names for odors. However, they started from an initially lower level of semantic knowledge of test odors.

Engen and Engen (1997) reviewed language development studies in naturalistic settings and found that (i) research of the development of the lexicon revealed that children are more concerned with color, size and location of objects than with smells and (ii) that there are virtually no examples of children spontaneously using the perception verb ‘smell’ to respond to odor experiences.

Although acquisition of verbal labels may be incidental and may thus proceed slowly during child development in a natural setting, children in the age range of 4–11 years have already acquired a substantial odor vocabulary. They are capable of using this semantic knowledge for encoding olfactory information and thus semantic encoding of odors is important for odor memory processes during early stages of childhood. This was clearly indicated by stepwise multiple regression analysis showing that consistent verbal labeling of odors is a good predictor of odor memory performance in children. Our data show that, once a child has named an odor consistently, he or she will remember this odor very well.

In summary, we confirmed that odor naming and odor memory were less developed in children. Two hypotheses are put forward to explain this phenomenon. First, a reasonable explanation could be that children may not yet have learned some of the verbal descriptors, and thus a certain odor is not identified correctly because the odor-related vocabulary is missing in semantic memory. Second, children have not had the opportunity to smell all the presented odors previously, and consequently the odors are unfamiliar to them. Thus, no memory trace in semantic memory is available. Whatever the reason, it is important to note that olfactory sensitivity is not impaired in children, and thus cannot account for poor odor naming and odor memory performance. Thus, we suggest that children have the capacity to detect odors in a comparable fashion to adults. However, naming of odorants slowly develops from childhood to adulthood and as a consequence episodic odor recognition memory of children is inferior than that of adults.

The elderly population in our study also showed clear-cut results. Performance was markedly reduced in the elderly for odor identification, odor memory and consistency of label use. For the measure of olfactory threshold we observed no statistical difference. However, compared with children a trend was detected (P < 0.06), indicating that the elderly also experienced a loss of olfactory sensitivity.

The mechanism of the olfactory loss in the elderly is not well understood. There is evidence that physiological and neuropathological changes in the olfactory system, such as age-related changes in the nasal cavity, and alterations in the olfactory mucosa and the olfactory bulb, are a common feature of growing older (Doty, 1991). On the other hand, impaired cognitive abilities could also be a major factor contributing to the decreased performance of the elderly in olfactory behavioral tests. For example, it is clear that cognitive capabilities decrease in the elderly, especially memory functions. Some cognitive processes involve more effortful processing than others (e.g. recall versus recognition), thus older people are relatively penalized when such processing is required (Craik, 1983). Further studies of olfactory functions in elderly populations should include naming and memory tests in other modalities in order to establish the relationship between olfaction and cognition in the elderly.

An interesting question concerns the turning point of olfactory functions in children and elderly. As our analysis demonstrated, there was no difference for olfactory threshold, odor memory and odor identification between children aged 4–8 years and aged 9–11 years, thus olfactory functions may develop at some point earlier than the age groups tested. Young adults are best at olfactory sensitivity, odor identification and odor memory; middle-aged adults experience a gradual decline in their olfactory capabilities until the age of >60 years, when there is a clear loss of olfactory identification ability and odor memory. The decrement of olfactory threshold is not as dramatic. However, elderly subjects aged >78 years also show considerable odor detection impairment.

As demonstrated in recent studies (Larsson and Bäckman, 1993; Larsson, 1997a), we also found that odor naming and odor memory were strongly related. However, our analysis indicated consistency of label use to be the main predictor of odor memory instead of odor identification ability. This is a new finding. Thus, naming a particular odor, both at learning and testing with the same label, independent of the ecological correctness of this label, determines odor memory performance for that odor in children, young adults and middle-aged adults, i.e. the personally generated label is more important for odor recognition than the ecological name of the odor. As has been pointed out by Engen (1982), the link between odor perception and language may be weak. Odor names are somewhat arbitrary and artificial. However, odor identification and consistency of label use are interrelated, indicating that a rich semantic trace of an odor sensation enhances consistent odor naming and subsequently odor recognition.

Our data suggest that there is a shift of olfactory processing in the elderly. Whereas in children and young adults, consistency of label use—that is, verbal naming context—is the main predictor of odor memory, in the elderly odor identification ability becomes the main predictor. However, the detection threshold was marginally significantly correlated with odor memory, indicating that primary sensory processes might be responsible for the poor odor memory in elderly subjects. It appears that children and young adults are able to successfully use consistent labeling—that is, generating the same verbal tag both at learning and testing—as a memory aid. In contrast, due to their slightly elevated threshold, the elderly no longer have the ability to discriminate odors as accurately as the young, and thus odors are no longer consistently named. This considerably alters their ability to remember odors because semantic processes are an important part of odor memory. As a consequence, the elderly remember only familiar odors they can also correctly identify.

An interpretation of the results of multiple stepwise regression analysis for the whole sample indicates an association between odor identification and consistency of label use—that is, 'semantic encoding' and odor memory. However, ANCOVA results show that large parts of the variance of odor memory cannot be explained by olfactory threshold, consistency of label use or odor identification alone, indicating that other factors must also be involved in odor memory processes. We suggest that familiarity judgements on the basis of perceptual aptitude are important determinants of odor memory, as has been suggested by dual-process models of recognition memory for other stimuli as well (Mandler, 1980).

To study dual-process memory the olfactory modality may be particularly rewarding because odors produce a prominent tip-of-the-nose phenomenon (Lawless and Engen, 1977) and unfamiliar odors may be remembered quite well (Engen and Ross, 1973). For instance, recent evidence showed that odors can be remembered quite well without adequate verbal labeling. Earlier reports documented that giving an odor at presentation and testing the same verbal tag results in a recognition accuracy of 87% (Lehrner, 1993). However, giving an odor different labels at presentation and testing is indicative of somewhat different semantic encoding, and still produces recognition rates above chance, with ~70% correct recognition (Lehrner, 1993). Such processing of olfactory stimuli may be similar to the experimental approach of the 'remember' and 'know' paradigm (Tulving, 1985). According to this distinction, recognition measured by a 'remember' response indicates that recognizing the test item brings to mind some conscious recollection of its prior occurrence in the learning list, such as an association it has triggered. A 'know' response is assumed to indicate that recognizing the item brings to mind a feeling of familiarity. That is, the subject is able to tell that a given item has previously been presented, but does not have a recollection of its prior occurrence in the study list (Mäntlya, 1993). Remember/know experiments showed consistently better recognition for the remember items. However, 'know' items were remembered above chance level as well (Rajaram, 1993).

Recent research suggested that the increase in false alarm rate in the elderly may be related to the fact that they rely less on conscious recollection in recognition experiments than on perceived familiarity, that is, the feeling of having had an item before but no conscious recollection of that particular item (Bartlett *et al.*, 1991). False alarm rate and hit rate analysis showed straightforward results for the elderly. They had higher false alarm rates and lower hit rates than young adults. This finding is consistent with several previous studies for olfactory stimuli (Larsson and Bäckman, 1993; Murphy *et al.*, 1997) and for faces and songs (Bartlett *et al.*, 1991; 1989; 1995). The response criterion did not differ between young adults and the elderly, indicating no difference in response behavior for the two study groups. However, response criterion did differ between younger and older elderly (Table 2), indicating a more liberal response criterion for the older elderly. We also found a negative correlation between olfactory threshold and false alarm rate in the elderly, showing that with decreased olfactory sensitivity the elderly may not discriminate the odors properly and thus tend to call a new odor old. Thus, our data suggest that recognition judgements in the elderly may be based to a large extent on perceived familiarity and such perceptually driven processing is dependent on olfactory sensitivity. In contrast to the elderly, there is no significant correlation between olfactory threshold and false alarm rate in children, young adults and middle-aged adults. Hit rate, false alarm rate and response criterion did not differ between children and young adults, indicating that basically the same motivational factors regarding olfaction are at work in the three study groups. The finding that false alarm rate in children is not significantly different from young adults indicates that children may rely more on conscious recollection. However, their ability to label odors consistently is significantly poorer compared with young adults. Thus, children may be in between young adults and the elderly in using perceived familiarity for recognition of odors.

Our data suggest that recognition of odors may involve explicit, context-dependent memory processes and implicit, data-driven memory processes. The investigation of olfactory perceptual fluency for odor memory processes and its incorporation into modern memory concepts of explicit/implicit memory (Schacter, 1990; DeSchepper and Treisman, 1996; Snodgrass *et al.*, 1996) seems worthwhile for the future.

Acknowledgements

We would like to thank Ms Sylvia Philipp for her generous cooperation in the conduct of this study and Prof. Trygg Engen for providing the initial stimulating ideas for this experiment. We would also like to thank Ms Maggie Lee Huckabee for making helpful comments on earlier drafts of this paper.

References

Bartlett, J.C. and **Leslie, J.E.** (1986) *Aging and memory for faces versus single views of faces*. Mem. Cogn., 14, 371–381.

Bartlett, J.C., Leslie, J.E., Tubbs, A. and **Fulton, A.** (1989) *Aging and memory for pictures of faces*. Psychol. Aging, 4, 276–283.

Bartlett, J.C., Strater, L. and **Fulton, A.** (1991) *False recency and false fame of faces in young adulthood and old age*. Mem. Cogn., 19, 177–188.

Bartlett, J.C., Halpern, A.R. and **Dowling, W.J.** (1995) *Recognition of familiar and unfamiliar melodies in normal aging and Alzheimer's disease*. Mem. Cogn., 23, 531–546.

Cain, W.S. (1979) *To know with the nose: keys to odor identification*. Science, 203, 467–470.

Cain, W.S., Gent, J.F., Goodspeed, R.B. and **Leonard, G.** (1988) *Evaluation of olfactory dysfunction in the Connecticut Chemosensory Clinical Research Center*. Laryngoscope, 98, 83–88.

Cain, W.S., Stevens, J.C., Nickou, C.M., Giles, A., Johnston, I. and **Garcia-Medina, M.R.** (1995) *Life-span development of odor identification, learning, and olfactory sensitivity*. Perception, 24, 1457–1472.

Craik, F.I.M. (1983) *On the transfer of information from temporary to permanent memory*. Phil. Trans. Roy. Soc. Lond., 302, 341–359.

Davis, R.G. (1975) *Acquisition of verbal associations to olfactory stimuli of varying familiarity and to abstract visual stimuli*. J. Exp. Psychol.: Hum. Learn. Mem., 104, 143–142.

Davis, R.G. (1977) *Acquisition and retention of verbal associations to olfactory and abstract visual stimuli of varying similarity*. J. Exp. Psychol.: Hum. Learn. Mem., 3, 37–51.

DeSchepper, B. and **Treisman, A.** (1996) *Visual memory for novel shapes: implicit coding without attention*. J. Exp. Psychol: Learn. Mem. Cogn., 22, 27–47.

DeWijk, R. and **Cain, W.S.** (1994) *Odor identification by name and by edibility: life-span development and safety*. Hum. Factors, 36, 182–187.

Dorries, K.M., Schmidt, H.J., Beauchamp, G.K. and **Wysocki, C.J.** (1989) *Changes in sensitivity to the odor of androstenone during adolescence*. Devl Psychobiol., 22, 423–435.

Doty, R.L. (1991) *Influences of aging on human olfactory function*. In Laing, D.G. Doty, R.L. and Breipohl, W. (eds), The Human Sense of Smell. Springer-Verlag, Berlin, pp. 155–163.

Doty, R.L., Shaman, P., Applebaum, S.L., Giberson, R., Sikorski, L. and **Rosenberg, L.** (1984) *Smell identification ability: changes with age*. Science, 226, 1441–1443.

Doty, R.L. Applebau, S. Zusho, H. and **Settle, R.G.** (1985) *Sex differences in odor identification ability: a cross cultural analysis*. Neuropsychologia, 23, 667–672.

Engen, T. (1982) The Perception of Odors. Academic Press, Toronto.

Engen, T. (1986) *Children's sense of smell*. In Meiselman, H.L. and Rivlin, R.S. (eds), Clinical Measurement of Taste and Smell. Macmillan, New York, pp. 316–317.

Engen, T. and **Engen E.** (1997) *Relationship between development of odor perception and language*. Enfance, 1, 125–140.

Engen, T. and **Ross, B.M.** (1973) *Long-term memory of odors with and without verbal descriptions*. J. Exp. Psychol., 100, 221–227.

Eskenazi, B., Cain, W.S. and **Friend, K.** (1986) *Exploration of olfactory aptitude*. Bull. Psychon. Soc., 24, 203–206.

Ferris, S.H., Crook, T., McCarthy, M. and **Rae, D.** (1980) *Facial recognition memory deficits in normal aging and senile dementia*. J. Gerontol., 35, 707–714.

Herz, R.S. and **Engen, T.** (1996) *Odor memory: review and analysis*. Psychon. Bull. Rev., 3, 300–313.

Koelega, H.S. and **Köster E.P.** (1974) *Some experiments on sex differences in odor perception*. Ann. N.Y. Acad. Sci., 237, 234–246.

Larsson, M. (1997a) *Age-related differences in episodic odor recognition: the role of access to specific odor names*. Memory, 5, 361–378.

Larsson, M. (1997b) *Semantic factors in episodic recognition of common odors in early and late adulthood: a review*. Chem. Senses, 22, 623–633.

Larsson, M. and **Bäckman, L.** (1993) *Semantic activation and episodic odor recognition in young and older adults*. Psychol. Aging, 8, 582–588.

Lawless, H. and **Engen, T.** (1977) *Associations to odors: interference, mnemomics and verbal labeling*. J. Exp. Psychol.: Hum. Learn. Mem., 3, 52–59.

Lehrner, J. (1993) *Gender differences in long-term odor recognition* *memory: verbal versus sensory influences and consistency of label use*. Chem. Senses, 18, 17–26.

Lehrner, J.P., Kryspin-Exner, I. and **Vetter, N.** (1995a) *Higher olfactory threshold and decreased identification ability in HIV-infected persons*. Chem. Senses, 20, 325–328.

Lehrner, J.P., Brücke, T., Dal-Bianco, P., Gatterer, G. and **Kryspin-Exner, I.** (1997) *Olfactory functions in Parkinson's disease and Alzheimer's disease*. Chem. Senses, 22, 105–110.

Lyman, B.J. and **McDaniel, M.A.** (1986) *Effects of encoding strategy on long-term memory for odors*. Quart. J. Exp. Psychol., 38A, 753–765.

Lyman, B.J. and **McDaniel, M.A.** (1990) *Memory for odors and odor names: modalities of elaboration and imagery*. J. Exp. Psychol.: Learn. Mem. Cogn., 16, 656–664.

Mandler, G. (1980) *Recognizing: the judgement of previous occurrence*. Psychol. Rev., 87, 252–271.

Mäntyla, T. (1993) *Knowing but not remembering: adult age differences in recollective experience*. Mem. Cogn. 21, 379–388.

Murphy, C. (1986) *Taste and smell in the elderly*. In Meiselman, H.L. and Rivlin, R.S. (eds), Clinical Measurement of Taste and Smell. Macmillan, New York, pp. 343–371.

Murphy, C., Cain, W.S., Gilmore, M.M. and **Skinner, B.** (1991) *Sensory and semantic factors in recognition memory or odors and graphic stimuli: elderly versus young persons*. Am. J. Psychol., 104, 161–182.

Murphy, C., Nordin, S. and **Acosta, L.** (1997) *Odor learning, recall and recognition memory in young and elderly adults*. Neuropsychology, 11, 126–137.

Perry, J.D., Frisch, S., Jafek, B. and **Jafek, M.** (1980) *Olfactory detection thresholds using pyridine, thiophene, and phenylethyl alcohol*. Otol. Head Neck Surg., 88, 778–782.

Porter, R.H. (1991) *Human reproduction and the mother–infant relationship: the role of odors*. In Getchell, T.V., Doty, R.L., Bartoshuk, L.M. and Snow, J.B. (eds), Smell and Taste in Helath and Disease. Raven Press, New York, pp. 429–442.

Rabin, M.D. and **Cain, W.S,** (1984) *Odor recognition: familiarity, identifiability, and encoding consistency*. J. Exp. Psychol: Learn. Mem. Cogn., 10, 316–325.

Rajaram, S. (1993) *Remembering and knowing: two means of access to the personal past*. Mem. Cogn., 21, 89–102.

Richman, R.A. Wallace, K. and **Sheehe, P.R.** (1995) *Assessment of an abbreviated odorant identification task for screening: a rapid screening device for schools and clinics*. Acta Paed., 84, 434–437.

Rothschild, M.A., Myer, C.M. and **Duncan, H.J.** (1995) *Olfactory disturbance in pediatric tracheotomy*. Otol. Head Neck Surg., 111, 71–76.

Schaal, B. (1988) *Olfaction in infants and children: developmental and functional perspectives*. Chem. Senses, 13, 145–190.

Schab, F.R. (1991) *Odor memory: taking stock*. Psychol. Bull., 2, 242–251.

Schab, F.R. and **Crowder, R.G.** (1995) Memory for Odors. Lawrence Erlbaum Associates, Hilldale, NJ.

Schacter, D.L. (1990) *Perceptual representation systems and implicit memory: toward a resolution of multiple memory systems debate*. Ann. N.Y. Acad. Sci., 608, 543–571.

Schemper, T.S., Voss, S. and **Cain, W.S.** (1981) *Odor identifiation in young and elderly persons. Sensory and cognitive limitations*. J. Gerontol., 36, 446–42.

Schiffman, S. and **Pasternak M.** (1979) *Decreased discrimination of food odors in the elderly*. J. Gerontol., 34, 73–79.

Schiffman, S.S., Moss, J. and **Erickson, R.P.** (1976) *Thresholds of food odors in the elderly*. Exp. Aging Res., 2, 389–398.

Schmidt, H.J. and **Beauchamp, G.K.** (1988) *Adult-like odor preferences and aversions in three-year-old children*. Child Dev., 59, 1136–1143.

Snodgrass, J.G. and **Corwin, J.** (1988) *Pragmatics of measuring recognition memory: applications to dementia and amnesia*. J. Exp. Psychol.: Gen., 117, 34–50.

Snodgrass, J.G., Hirshman, E. and **Fan, J.** (1996) *The sensory match effect in recognition memory. Perceptual fluency or episodic trace?* Mem. Cogn., 24, 367–383.

Solbu, E.H., Jellestad F.K. and **Straetkvern, K.O.** (1989) *Children's sensitivity to odor of trimethylamine*. J. Chem. Ecol., 16, 1829–1840.

Stevens, J.C. and **Cain, W.S.** (1985) *Age-related deficiency in the perceived strength of six odorants*. Chem. Senses, 10, 517–529.

Stevens, J.C. and **Cain, W.S.** (1987a) *Old-age deficits in the sense of smell as gauged by thresholds, magnitude matching and odor identification*. Psychol. Aging, 2, 36–42.

Stevens, J.C., Cain, W.S. and **Weinstein, D.E.** (1987b) *Aging impairs the ability to detect gas odor*. Fire Technol., 23, 198–204.

Sullivan, R., Taborsky, S., Mendoza, R., Itano, A., Leon, M., Cotman, C., Payne, T. and **Lott, I.** (1991) *Olfactory classical conditioning in neonates*. Pediatrics, 87, 511–518.

Tulving, E. (1985) *Memory and consciousness*. Can. Psychol., 26, 1–12.

Wysocki, C.J. and **Pelchat, M.L.** (1993) *The effects of aging on the human sense of smell and its relationship to food choice*. Crit. Rev. Food Sci. Nutr., 33, 63–82.

Accepted February 17, 1999