Demographic and Cognitive Predictors of Cued Odor Identification: Evidence from a Population-based Study

Maria Larsson[1,2], Lars-Göran Nilsson[1,2], Jonas K. Olofsson[3] and Steven Nordin[3]

[1]Department of Psychology, Stockholm University, S-106 91 Stockholm, Sweden, [2]Centre for Advanced Study, Oslo, Norway and [3]Department of Psychology, Umeå University, Umeå, Sweden

Correspondence to be sent to: Dr Maria Larsson, Department of Psychology, Stockholm University, Frescati Hagväg 14, S-106 91 Stockholm, Sweden. e-mail: maria.larsson@psychology.su.se

Abstract

This study investigated demographic and cognitive correlates of cued odor identification in a population-based sample from the Betula project: 1906 healthy adults varying in age from 45 to 90 years were assessed in a number of tasks tapping various cognitive domains, including cognitive speed, semantic memory and executive functioning. The results revealed a gradual and linear deterioration in cued odor identification across the adult life span. Overall, females identified more odors than men, although men and women performed at the same level in the oldest age cohort (85–90 years). Hierarchical regression analyses revealed that age, sex, education, cognitive speed and vocabulary were reliable correlates of performance in the odor identification task. In addition, age-related deficits in the included demographic and cognitive variables could not fully account for the observed age-related impairment in identification, suggesting that additional factors are underlying the observed deterioration. Likely candidates here are sensory abilities such as olfactory detection and discrimination.

Key words: Betula project, individual differences, odor identification

Introduction

Research indicates that aging is associated with impairment in identifying olfactory information (e.g. Doty *et al.*, 1984; Larsson *et al.*, 2000). Aging effects are present in both free identification measures (e.g. Larsson and Bäckman, 1997) and in tasks where multiple choices of possible odor names are available although performance in general is higher when cues are provided (e.g. Stevens and Cain, 1987; Larsson *et al.*, 1999). Most of the available data are based on studies contrasting one group of younger adults with a group of older adults, with only a few exceptions (e.g. Doty *et al.*, 1984; Kobal *et al.*, 2000). Only two studies have addressed odor identification ability using population-based samples. In investigating individuals aged 53–97 years, aging, male-gender, current smoking, stroke, epilepsy and nasal congestion or upper respiratory tract infection were reported to be associated with poor odor identification (Murphy *et al.*, 2002). In the second population-based study of individuals aged 20–92 years, aging, male-gender, nasal polyps and diabetes were found to be risk factors for olfactory dysfunction assessed with an odor identification test (Brämerson *et al.*, 2004).

The main aim in the present work was to extend these previous studies by shifting focus to cognitive predictors for odor identification. Thus, apart from examining changes in the verbalization of olfactory information over the adult life span of middle age to elderly (45–90 years) using population-based samples of healthy individuals (*n* = 1906), a goal was to localize cognitive and demographic factors that may contribute to successful identification in general and for age-related deficits in odor identification in particular.

Knowledge is sparse regarding relationships between individual differences in demographic factors, cognitive abilities and proficiency in odor identification tasks. However, one demographic characteristic known to influence odor identification is sex. Research indicates that females are better in identifying olfactory information than are males (for a review, see Brand and Millot, 2001). This superiority has been proven to be age invariant with higher performance in girls than in boys and higher identification rates among elderly women as compared with elderly men (Corwin *et al.*, 1995; Richman *et al.*, 1995). Interestingly, using the UPSIT, Ship *et al.* (1996) reported that the pattern of deterioration across the life span may vary as a function of sex, such that males deteriorated earlier in life than females. In line with these behavioral data, electrophysiological data reported by Morgan *et al.* (1997) show that older males demonstrate smaller peak amplitudes in olfactory event-related potential as compared with younger age groups and a group of older

women. Based on these findings, we expected a general performance superiority among females and we were particularly interested in evaluating any potential age by sex interactions in the examined age span.

Regarding relationships between various cognitive abilities and odor identification, Larsson *et al.* (2000) reported that proficiency in cognitive measurements tapping semantic memory functions (e.g. analogies, information) was positively related to cued odor identification performance, although individual variations in chronological age, sex and education were controlled for. Tasks tapping short-term memory, visuo-spatial functioning and episodic memory performance were unrelated to identification. These results were recently corroborated by Economou (2003), who reported that odor identification performance in the UPSIT, was reliably associated with verbal memory after accounting for demographic variables. Taken together, this pattern of results suggests that semantic memory (i.e. crystallized intelligence) and odor identification draw on the same cognitive domain.

In a related vein, it is of interest to note that episodic odor recognition memory has been shown to be dependent upon semantic factors, such as familiarity and odor identification and that older adults difficulties' in identifying olfactory information is a crucial factor for the aging-related impairment in odor memory (Larsson, 1997; Lehrner *et al.*, 1999). Given that age deficits in odor naming are highly prevalent and that they mediate age-related deficits in odor memory, it is of further interest to consider potential explanations for older adults' problems in identifying odors.

In the present study, 1906 healthy adults, screened for dementia and anosmia, were assessed in a cued odor identification task together with a number of tasks tapping different cognitive domains (see Nilsson *et al.*, 1997). The sample was population-based in that the participants were randomly selected from the population. Based on these data we examined: (i) the general influence of age and sex on odor identification across the adult life span; (ii) the relative predictive value of individual differences in demographic and cognitive variables on odor identification; and (iii) the localization of demographic and cognitive factors that may contribute to the aging-related deterioration in identification of olfactory information.

Materials and methods

Participants

The data considered here are derived from the third wave of data collection in the Betula study collected in 1998–2000, which is a large scale population-based longitudinal study focusing on aging, memory and health (Nilsson *et al.*, 1997). Data from three independent samples, with complete scores were aggregated yielding a total sample of 2047 individuals from 10 different age cohorts (45, 50, 55, . . . , 90 years). Participants were randomly drawn from the population

registry in Umeå, a city of ~100 000 inhabitants. The participants considered here were all screened for early dementia (Folstein *et al.*, 1975; Devanand *et al.*, 2000) and mental retardation by having omitted subjects with an MMSE score <24 ($n = 106$). Also, subjects were interviewed regarding olfactory functioning. Persons with severe olfactory dysfunction or anosmia were excluded ($n = 35$) if they responded 'Worse than normal' on the question 'How is your ability to perceive weak odors' (additional respose alternatives were 'Normal' and 'Better than normal') in combination with an identification score at chance level (<3). The final sample consisted of 1906 healthy adults screened for cognitive and olfactory dysfunction.

All subjects were assessed in two sessions, 1 week apart. The first session, which was conducted by a nurse, involved an extensive health examination, including blood sampling. In addition, an interview about health status was conducted and questionnaires concerning social background variables and critical life events were distributed. Some cognitive tests were also administered during this session. The second session was devoted exclusively to assessment of memory and other cognitive functions and was carried out by persons well trained in memory testing. The duration of each session was ~2 h. For the statistical analyses, the study sample was divided into five age groups: 45 and 50; 55 and 60; 65 and 70; 75 and 80; and 85 and 90 years. Sex distribution and educational background across these age groups are provided in Table 1. An analysis of variance (ANOVA) indicated an effect of age for educational level [$F(4,1901) = 199.12$, MSE = 11.50, $P < 0.001$, $\eta^2 = 0.27$]. *Post hoc* Scheffe tests showed that educational level differed reliably between all age groups (Ps < 0.01), except between the 75–80 and 85–90-year-olds, where years of formal schooling were of equal length ($P > 0.90$). The age groups did not differ in sex distribution ($F < 1$).

Criterion task

Odor identification

The odorous stimuli used were almond (bitter), anise, apple, cinnamon, clove, juniper berry, lilac, lemon, orange, pine-needle, tar, vanilla and violet. These stimuli are perceptually

Table 1 Subject characteristics

Age group (years)	Male/female (*n*)	Years of education (mean ± SD)
45–50	166/167	13.66 (2.75)
55–60	202/222	12.14 (3.83)
65–70	230/261	9.89 (3.69)
75–80	168/239	8.02 (3.07)
85–90	102/149	7.70 (3.23)
45–90	868/1038	–

fairly strong in intensity (Nordin *et al.*, 1998) and can be considered to represent a wide range of qualities, such as floral, citrous, non-citrous fruity, sweet, woody, spicy and minty. Tar was a virtual product, whereas the remaining stimuli (see Bende and Nordin, 1997) were natural etheric oils (Stockholm Ether and Essence Manufactory, Stockholm, Sweden). The liquid odorant was injected into a tampon filled to saturation and placed in an opaque, 80 ml glass jar. For each stimulus the subject was provided with a written list of the four response alternatives (Bende and Nordin, 1997) from which to choose the most appropriate item for identification. The stimuli were presented birhinally 1–2 cm under the participant's nose for as long as required to accomplish the task. The 13 odorants (as well as ammonia, vinegar and peppermint, excluded in the present study due to having a significant trigeminal impact) have previously been demonstrated to constitute a valid and reliable test of odor identification ability, called the Scandinavian Odor Identification test (SOIT; Nordin *et al.*, 1998). The presently used version of the SOIT differed from the original version in that the response alternatives were perceptually very similar to corresponding test odorant, making the test relatively difficult in order to avoid ceiling effects. The stimulus order was randomized between subjects by randomly assigning one out of ten different stimulus orders to each subject and there was a 30 s interstimulus interval between stimuli to limit the effects of adaptation.

Cognitive speed

Speed of information processing

The Letter–Digit Substitution test, which is a modified version of the Digit–Symbol Substitution test (Wechsler, 1981; Salthouse, 2000), was used as an index of processing speed. The test comprises a reference table of nine letter–digit pairings. Below these, the letters appear randomized in rows with black boxes beneath. Participants are required to write the digits in the empty boxes, according to the reference table. Following a brief practice trial, participants were allowed 60 s to complete as many letter-digit pairings as possible. The number of correct pairings served as the dependent measure.

Semantic memory

Verbal fluency

One task assessing letter fluency proficiency was used. Here, participants were instructed to produce as many words as possible in one minute, beginning with the letter A (cf. Benton and Hamsher, 1976). Category fluency was assessed by means of a task in which participants were asked to generate as many professions as possible during 1 min, beginning with the letter B.

Vocabulary

A revised version of the Dureman and Sälde (1959) synonym test was used to assess general verbal knowledge (Nilsson *et al.*, 1997). The test was a 30 item multiple-choice test. Participants were instructed to select a synonym for each test word out of five alternatives (Dureman and Sälde, 1959). The test is self-paced and took ~10 min to complete.

Executive functioning

Block design

The obtained raw scores from the Block Design test from the Wechsler Adult Intelligence Scale—Revised (Wechsler, 1981) were used. In this task, participants are, under speeded conditions, required to place red and white blocks such that they form the same pattern shown on a target paper. Performance in this task is generally construed as measuring spatial visualization ability and poses demands on executive functioning.

Tower of Hanoi

We examined performance in a five-disk version of the Tower of Hanoi (TOH) puzzle, assumed to reflect executive functioning and problem solving (Lezak, 1995). The number of moves necessary to complete the task was the dependent measure.

Procedure

As noted, the present study is a part of a larger battery of cognitive tasks (for a full description, see Nilsson *et al.*, 1997). The odor identification task was carried out at the end of the second test session. The entire session took ~2–2.5 h to complete.

Results

Odor identification

Proportions of correct odor identification performance were submitted to a 5 (age group) × 2 (sex) ANOVA. There was no effect of stimulus order in the ANOVA and we therefore collapsed the data across this variable. The mean proportions of odor identification performance across age groups and sex are displayed in Figure 1. The results from the ANOVA indicated a reliable age-related deterioration in odor identification performance [$F(4,1896) = 90.87$, MSE = 0.024, $P < 0.0001$, $\eta^2 = 0.18$] and that women performed higher than men [$F(1,1896) = 35.16$, MSE = 0.024, $P < 0.0001$, $\eta^2 = 0.02$]. *Post hoc* Scheffe tests indicated that all age groups differed reliably ($Ps < 0.01$). The interaction between age and sex did not reach conventional levels of significance [$F = (4,1896) = 2.21$, MSE = 0.024, $P < 0.065$, $\eta^2 = 0.005$. However, a closer visual inspection of the respective mean values in each age group motivated a more specific testing of the obtained mean differences between men and women. These analyses indicated reliable sex differences

favoring women in the 45–50, 55–60 and 65–70 age cohorts ($Ps < 0.001$). In the 75–80 age cohort, women identified more odors than men, although the sex difference was less pronounced ($P < 0.03$). In the oldest age cohort, men and women performed at the same level ($P > 0.90$).

Individual differences and odor identification

To determine the relationships of the demographic and cognitive variables to cued odor identification performance, product-moment correlations were first calculated. The results from the correlational analysis are shown in Table 2. In agreement with previous research, odor identification was negatively correlated with age (e.g. Murphy *et al.*, 2002). In addition, female sex, education, cognitive speed, verbal fluency and vocabulary were related to proficiency in odor
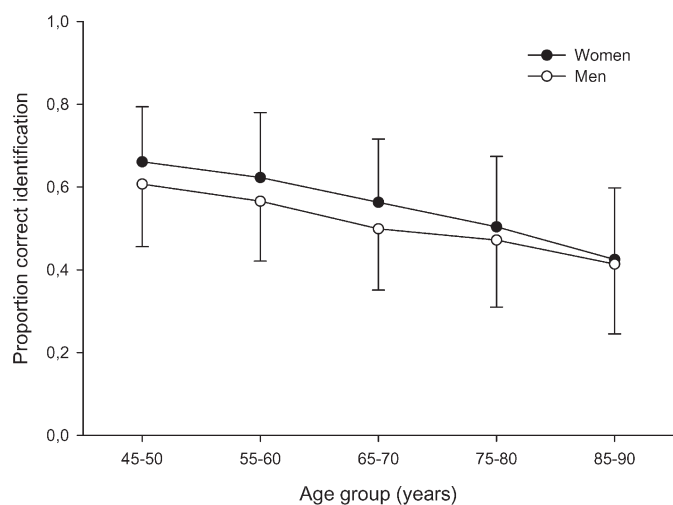
identification. Also, performance in Block design and Tower of Hanoi was related to identification performance ($Ps > 0.01$).

The main analyses consisted of two sets of hierarchical multiple regressions using the demographic and cognitive variables as predictor variables and odor identification as the criterion measure. In the first regression, age was entered first, followed by the demographic block (i.e. sex, education). In the third step, cognitive speed was entered, followed by the block of semantic memory tasks (i.e. vocabulary, verbal fluency). The tasks tapping executive functioning (i.e. Block design, Tower of Hanoi) were entered as a final block. The order of entry of the cognitive variables was motivated by the strength of correlation with the criterion measure. In the second regression, the variables were entered in a manner identical with the first regression, with the exception of age being entered as the last variable. In this way we could determine the relative contribution of each predictor variable as a function of variable entry. This procedure also allowed us to determine the extent to which the included demographic and cognitive variables could account for the age-related deterioration in odor identification. The results from the series of regression analyses are shown in Tables 3 and 4. For each analysis, R^2, cumulative R^2 after adding each predictor variable, standardized regression coefficients (β) and P-values are displayed.

The first regression analysis showed that age accounted for a significant portion of the variance in identification performance (12%). Both sex and education contributed significantly to the variance in identification (2%). Of the cognitive tasks, speed (1%) and vocabulary (2%) made independent contributions to performance, whereas executive functioning proved unrelated to identification proficiency.

The main aim in the second regression analysis was to localize factors that may account for the age deterioration in identification. As is shown in Table 4, the results indicated

Figure 1   Odor identification as a function of age and sex. Bars represent standard deviations.

Table 2   Intercorrelations among variables

	1	2	3	4	5	6	7	8	9	10
1. Age	–	−0.07**	−0.54**	−0.39**	−0.38**	−0.26**	−0.66**	−0.60**	0.33**	−0.39**
2. Sex		–	0.03	−0.02	−0.07*	−0.03	−0.07*	0.13**	−0.05*	−0.11**
3. Education			–	0.51**	0.47**	0.24**	0.53**	0.46**	−0.22**	0.28**
4. Vocabulary				–	0.52**	0.33**	0.51**	0.49**	−0.16**	0.31**
5. Letter fluency					–	0.38**	0.54**	0.42**	−0.20**	0.25**
6. Category fluency						–	0.35**	0.32**	−0.13**	0.15**
7. Cognitive speed							–	0.63**	−0.38**	0.34**
8. Block design								–	−0.28**	0.26**
9. Tower of Hanoi									–	−0.11**
10. Odor identification										–

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

Table 3 Hierarchical regression analysis for predicting odor identification

Predictor	Incr. R^2	Cum. R^2	β	P
1. Age	0.12	0.12	–0.34	0.000
2. Demographic variables	0.02	0.14		
Sex			–0.12	0.000
Education			0.09	0.006
3. Cognitive speed	0.01	0.15	0.13	0.001
4. Semantic memory	0.02	0.17		
Vocabulary			0.15	0.000
Letter fluency			0.03	n.s.
Category fluency			0.01	n.s.
5. Performance	0.00	0.17		
Block design			0.00	n.s.
Tower of Hanoi			0.02	n.s.

Table 4 Hierarchical regression analysis for identifying demographic and cognitive mediators of the age-related variance in odor identification

Predictor	Incr. R^2	Cum. R^2	β	P
1. Demographic variables	0.07	0.07		
Sex			–0.11	0.000
Education			0.24	0.000
2. Cognitive speed	0.05	0.13	0.26	0.000
3. Semantic memory	0.01	0.14		
Vocabulary			0.12	0.001
Letter fluency			0.03	n.s.
Category fluency			0.01	n.s.
4. Performance	0.00	0.14		
Block design			0.06	0.10
Tower of Hanoi			0.01	n.s.
5. Age	0.03	0.17	–0.26	0.000

that although the demographic factors, speed and vocabulary made a significant contribution to identification, these factors could not fully account for the observed age effect in identification, as chronological age still had a significant impact on identification proficiency ($P < 0.001$).

Together, the demographic and cognitive variables accounted for 17% of the variance in odor identification and explained 75% of the age-related variance in odor identification.

Discussion

The major objective of this study was to examine influences of age and sex on cued odor identification using three independent population-based samples. A further goal was to determine demographic and cognitive predictors of odor identification and to localize factors that may account for age deficits in identification performance.

Overall, the results indicate a linear, decreasing performance in odor identification across the adult life span. Overall, females identified more odors than men although the sex difference disappeared in the oldest age cohort (85–90 years). The regression analyses showed that age, sex, cognitive speed and vocabulary accounted for a statistically significant portion of the variance in identification performance. A finding of particular interest is that vocabulary, an index of general verbal knowledge, made an independent contribution to odor identification, although age, demographic factors and cognitive speed were controlled for. The observation that the tasks measuring executive functioning were unrelated to identification performance provides a strengthening of the view that semantic memory and verbalization of olfactory information draw on similar cognitive abilities (cf. Larsson et al., 2000; Economou, 2003). Also, it is worth noting that the second measure of semantic

memory, verbal fluency, did not share any common variance with identification when age, sex, speed and vocabulary, was under statistical control. One possible explanation for this outcome is that the two key processes subserving proficiency in verbal fluency, speed and word knowledge (e.g. Bolla et al., 1990; Lezak, 1995), were absorbed by the variance in the cognitive speed and vocabulary tasks, which were entered before fluency in the regression model.

A large number of studies have focused on various measures of speed as potential mediators of the relations between age and variables reflecting different forms of memory and cognition. This research has consistently shown that slower processing speed contributes to at least some of the age-related differences across a variety of different cognitive variables (Salthouse, 1996). Also, research suggests that a slowing in processing speed with increasing age may serve as an index for a slower propagation of neural impulses related to reductions in dendritic branching, decrements in the number of active synapses, or a loss of myelin (Salthouse, 2000). Evidence is yet sparse with regard to the role played by processing speed in the verbalization of olfactory information. However, given that odor identification poses demands on cognitive abilities (e.g. Larsson et al., 2000; Economou, 2003), it is not surprising that processing speed was localized as a significant factor for successful cued identification. Also, recent findings indicated that speed shared a reliable amount of the variation also in a free recall odor identification task and accounted for a significant proportion of the age-related variance in identification (Larsson and Bäckman, 2004). Thus, the present observations replicate these findings in showing that individual differences in processing speed made an independent contribution to identification, although age and demographic factors were statistically controlled for. This suggests that cognitive speed

draws on processes of additional importance for successful identification. Moreover, the present results extend previous findings in showing that the speed-identification relationship also is valid for cued odor identification.

With regard to demographic factors, level of education has been shown to exert a positive influence on both episodic and semantic memory performance (e.g. Nyberg *et al.*, 1996). In a similar vein, the present findings suggest that individuals with more education also identified more odors correctly. In addition, years of formal education also proved to account for a significant portion of the age-related variance in identification.

In congruence with previous findings, women identified more odors than men (e.g. Brand and Millot, 2001). The female superiority was valid throughout the adult life span (e.g. Doty *et al.*, 1984; Öberg *et al.*, 2002), although the observed sex difference decreased in size with increasing age. The specific source of the observed difference remains unclear but typical explanations for the female superiority in identification include sex differences in verbal abilities (Hyde and Linn, 1988), prior experience (Cain, 1982) and the modulating role of sex hormones on olfactory behavior (Doty *et al.*, 1981). Some recent findings suggest that experiential factors may play a more limited role in the observed sex difference in identification (Dempsey and Stevenson, 2002). As noted previously, both behavioral and physiological research has indicated that sex may influence the pattern of age-related olfactory decrements such that men deteriorate earlier in life than women (Ship *et al.*, 1996; Morgan *et al.*, 1997). Although the interaction between age and sex did not reach conventional levels of significance, specific testing within each age cohort indicated that females performed better in the younger age cohorts, whereas men and women in the oldest age cohort (85–90 years) identified equal numbers of odors. To understand more fully the reasons underlying age by sex interactions in olfactory functioning, further research is required. For example, the present findings are based on cross-sectional data, making it difficult to track true age by sex changes over the life span.

Numerous standardized tests of cued odor identification with response alternatives are available (e.g. Doty *et al.*, 1984; Cain, 1989; Nordin *et al.*, 1998; Thomas-Danguin *et al.*, 2001) that can be assumed to predominantly depend on and thus reflect, the olfactory functions of detection sensitivity and quality discrimination (Cain and Gent, 1991; Cain *et al.*, 1998; Dulay and Murphy, 2002; Larsson and Bäckman, 2004). Indeed, although sensory correlates were lacking in the present study, the rather high proportion of unexplained variance in odor identification favors the notion that sensory functions dominate in the task of cued odor identification. Apart from avoiding ceiling effects, the use of response alternatives in the present study that were perceptually similar to the corresponding test odorant may suggest that relatively high demands were placed on discriminative processes. However, it should be pointed out that the contribution of cognitive factors is considerably larger in free odor identification, since spontaneous identification poses higher cognitive demands (e.g. Larsson *et al.*, 2000; Larsson and Bäckman, 2004).

Several potential neuroanatomical explanations for the age-related decline in odor identification can be given. These include reduction with increased age in number, morphology and viability of receptor neurons and second-order neurons as well as broader tuning of receptor cells for discrimination (e.g. Paik *et al.*, 1992; Chen *et al.*, 1993; Loo *et al.*, 1996; Meisami *et al.*, 1998; Rawson *et al.*, 1998; Yousem *et al.*, 1998). In the higher-order olfactory areas, abnormal numbers of neurofibrillary tangles have been demonstrated in non-demented elderly in areas of major importance for odor processing, including the anterior olfactory nucleus and mesial temporal areas, particularly in the parahippocampal gyrus and hippocampus (Price *et al.*, 1991; Kovács, 2004).

In summary, the present results revealed a gradual and linear deterioration in verbalization of olfactory information across the adult life span in a large population-based sample involving 1906 persons. Overall, females identified more odors than men, although men and women performed at the same level in the oldest age cohort (85–90 years). In addition to demographic factors, cognitive speed and vocabulary were reliable correlates of identification in general, although these factors could not fully account for the well-documented age deterioration in odor identification.

Acknowledgements

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