Different forms of human odor memory: a developmental study

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Abstract

Recognizing odors is an important biological function, both in the animal kingdom as well as for humans. It has been debated whether there exist different forms of human odor memory. For verbal memory, the concept of recollection and familiarity for conscious and unconscious recognition is widely accepted. Here we introduce a similar model for human odor memory. We use a combination of an odor naming and odor recognition memory task to estimate the relationship between depth of processing and retention of olfactory information. A developmental approach with children, young adults, middle aged adults and elderly subjects was chosen in order to study the influence of age. Our results indicate the existence of two separable forms of odor memory depending on whether the odors were correctly or incorrectly named during the naming task. These two forms of odor memory were differently represented across the human age range. Intact familiarity-based memory was found in all age groups, whereas memory based on recollection was impaired in the elderly and not yet fully developed in children. Our data show, for the first time, two different forms of human odor memory across the human life span. © 1999 Elsevier Science Ireland Ltd. All rights reserved.

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Chemosensitivity developed at very early stages of evolution. Olfaction is very important in vertebrates, and a wealth of data on odor memory has accumulated from subhuman mammalian species [13]. Human and non-human primates share common principles of odor quality perception [10], and the importance of peri- and postnatal olfactory information [15,21], including olfactory classical conditioning in newborns, has been shown recently [19]. Furthermore, unconscious interindividual communication through body odor in man has been demonstrated [18] and it has been documented that 1–2% of the human genome is allocated to the coding of olfactory receptors [1].

The present study was conducted in order to investigate human odor memory, focusing on the influence of language on the storage and retrieval of olfactory information. This relationship is of special interest, since it is known that mesio-temporal and frontal cerebral structures are generally engaged in memory functions and at the same time, are also important for processing of olfactory information [12,17,22]. We have now obtained evidence of two different forms of odor memory. We found familiarity-based memory across the whole human life-span whereas memory based on recollection was not yet fully developed in children and substantially impaired in the elderly.

One hundred and thirty-seven subjects participated in the study, 51 males and 86 females. Subjects were split into five age groups: 20 young children aged 4–8 years (mean 6.8 ± 1.2), 21 older children aged 9–11 (mean 9.6 ± 0.7), 55 young adults from 18 to 30 years (mean 24.9 ± 2.7), 22 middle-aged adults from 31 to 57 (mean 40.7 ± 9.1) and 18 elderly subjects with an age range from 64 to 90 years (mean 77.8 ± 8.2). The children were from a Vienna Elementary School and the young subjects were mostly students of the University of Vienna. Elderly people were community-dwelling senior citizens of Vienna. All subjects gave informed consent. In the case of children, informed consent was obtained from parents or guardians.

In the first part of the experiment, we simply asked subjects to try to name common everyday odors. Subjects were successively presented with 10 odorants out of the 20 item odor pool. The subjects were asked to name the odor as precisely as possible using one word and to memorize the odor because they would be tested later to see how well they could remember the odors. The order of presentation was...
randomized within and between subjects. The test took approximately 30 min [11]. The response to each stimulus was categorized into three levels of correctness using the terminology described by Cain (1979) [2]. 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. spice for cloves) and a far miss, i.e. names quite far from veridical labels (e.g. lemon for coffee). Thus, correctly named odors were termed veridical and incorrectly named odors were termed far misses. In our analysis we did not include near miss responses because their frequency was too low for a meaningful statistical analysis. Olfactory identification ability was regarded to be a direct route to semantic knowledge about the presented odors, and thus indicative of the level of processing.

Without any associated information, the odor naming task proved to be surprisingly difficult and varied as a function of age. Young children, older children and elderly adults showed a low identification accuracy (35, 39 and 22%, respectively), whereas young and middle aged adults were better (60 and 55%). This is a robust finding which is consistent with other studies performed using different sets of odors [2,3].

The poor identification accuracy of children is probably due to the fact that they have not yet fully acquired their odor name lexicon. Such an interpretation is supported by other studies in which children’s visual naming of common objects was inferior compared to adults [3]. In a previous study, we showed that the olfactory sensitivity of the same group of children was comparable to young adults [11], indicating that poor naming ability cannot be attributed to sensory processes.

In the case of the elderly, one could argue that poor performance was due to either impaired olfactory function or impaired memory of odor names. Impaired odor naming in the elderly, however, seems to be due to their slightly decreased olfactory sensitivity [11] because in visual object naming they show almost no difficulties [3].

In a second stage of the experiment, after a retention interval of 15 min, subjects had to perform an odor old/new discrimination task. The previously presented odors were presented again together with an equal number of new odors, and subjects had to judge whether the odor item was old or new, and then try to name the odor. As described above, the label given for identification of new odors was scored for correctness.

Correctly recognized old odors and incorrectly recognized new odors were categorized depending on correctness of naming. The performance scores were corrected for guessing by subtracting false alarms from hits. The applied analysis revealed different patterns depending on age (Fig. 1A). Odors, which were not correctly named (far misses) elicited the same recognition performance across age groups (ANOVA; \( F(4, 132) = 2.5; P > 0.05 \)).

Recognition of odors which were correctly named (veridical naming), on the other hand, strongly depended on age (ANOVA; \( F(4, 132) = 19.4; P < 0.001 \)). Young adults showed the best memory performance for correctly named odors, whereas elderly adults performed poorest. Both children groups and middle aged adults were somewhat in between. See Fig. 1B for exact statistics.
We further analyzed the hit rates and false alarm rates for correctly and incorrectly named odors separately. Table 1 shows the results with exact statistics. Inspection of the hit rates for correctly named odors revealed a non-monotonic change of performance across age with young adults performing best. False alarm rates were in general rather low and did not differ significantly across age groups. Hit rates and false alarm rates for incorrectly named odors showed an inverse U-shaped function. Interestingly, the elderly showed the highest hit rate and false alarm rate indicating a strong tendency to call incorrectly named odors old.

Recent memory research shows that the recognition of a repeated verbal stimulus may depend on two different forms of memory processes. According to the 'dual process theory' [14], these forms are called 'familiarity', which is based on perceptual processing, and 'recollection', which includes the retrieval of contextual information. Familiarity judgements are made on the basis of a feeling, without specific information about the encoding episode, and thus relate to implicit or unconscious memory. Recollection is seen as a form of elaborate or conceptually driven process, and thus related to explicit or conscious memory. Such a dissociation between explicit and implicit memory for words has also been reported by means of event-related potentials [20].

It is known that implicit memory for words is intact in elderly people [7] as well as amnestic patients [16]. Furthermore, the level of processing during an encoding episode is shown to have a strong effect on which of the two forms of memory elicit a high recognition performance [4]. Semantic processing of words leads to a good memory performance whereas non-semantic processing leads to a rather poor memory performance [6].

Assuming that the name of an odor represents its semantic information, we interpret that correct naming of an odor is a high (cognitive) level of processing. Odors which cannot be correctly named are processed on a lower and more perceptual level. Our results suggest a model for odor recognition memory, similar to that for verbal recognition memory, where the level of processing has a strong influence on memory performance.

Odors which could not be correctly named (low processing level) were recognized equally well across age groups. This provides strong evidence that there is a familiarity-based recognition system which is equally intact in children, young adults and the elderly. This form of odor memory is interpreted as being related to perceptual processes.

Odors which were correctly named (high processing level) on the other hand, resulted in the best recognition performance in young adults, somewhat less in middle aged adults, and the poorest performance in elderly adults. These data indicate the existence of a recollection-based odor memory system which declines with age. Both children groups did not perform as well as young adults, probably because their explicit memory system is still developing. The poor odor memory for the elderly seems to be a combination of impaired odor naming capabilities due to their slightly decreased olfactory sensitivity and their poor capacity of using available semantic information in discriminating odors. Thus, compared with young adults the elderly do not use semantic labels of incorrectly named odors as efficiently and as a consequence they have a weakness in remembering whether they have experienced incorrectly named odors or not. In order to compensate for this weakness they have a strong tendency calling presented odors old.

Previously, the extent to which age-related olfactory differences are attributed either to sensory deficits or to cognitive limitations has been questioned [5,8]. Our results help to clarify the long standing issue of age-related differences in odor memory and its positive correlation to semantic (cognitive) processing [9,11]. First, our data demonstrate familiarity-based odor memory across the human age range, indicating retention of olfactory information without 'deep' verbal processing. Secondly, remembering semantically (deep) encoded olfactory information is clearly impaired in the elderly and still developing in children, demonstrating the importance of semantic processing for odor memory.

In conclusion, we found that the human memory for odors

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<th>Correct naming</th>
<th>Incorrect naming</th>
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<tr>
<td></td>
<td>Hits*</td>
<td>False alarms**</td>
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<td>Young children (1)</td>
<td>0.32</td>
<td>0.03</td>
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<td>Older children (2)</td>
<td>0.33</td>
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<td>Young adults (3)</td>
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<td>Middle-aged adults (4)</td>
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<td>Elderly (5)</td>
<td>0.18</td>
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*Mean proportions for each age group are shown. Results of analyses of variance and subsequent pair-wise comparisons using Scheffe’ post-hoc tests are also reported. **ANOVA: \( F(4,132) = 19.8; \ P < 0.001 \); significant Scheffe’ post-hoc pair-wise comparisons: (1 vs. 2; 2 vs. 3; 3 vs. 1, 2, 4, 5; 4 vs. 3, 5; 5 vs. 3, 4); ***ANOVA: \( F(4,132) = 1.9; \ P > 0.1 \); ****ANOVA: \( F(4,132) = 15.9; \ P < 0.001 \); significant Scheffe’ post-hoc pair-wise comparisons: (1 vs. 3; 2 vs. 3; 3 vs. 1, 2, 5; 4 vs. 5; 5 vs. 3, 4); *****ANOVA: \( F(4,132) = 16.7; \ P < 0.001 \); significant Scheffe post hoc pair-wise comparisons: (1 vs. 3, 5; 2 vs. 5; 3 vs. 1, 5; 4 vs. 5; 5 vs. 1, 2, 3, 4).
relies on at least two forms of recognition. One form of recognition is based on perceptual processing while the other is based on semantic (cognitive) processing. Thus, our results support and extend previous findings concerning the hypothesis of unconscious (perceptual) and conscious (cognitive) memories, and extend it to the olfactory modality.

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