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REVIEW ARTICLE

Semantic Factors in Episodic Recognition of Common Odors in Early and Late Adulthood: a Review

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Abstract

Information on long-term memory for common odors is discussed. Olfactory parameters (i.e. familiarity, recognition, identification) and their relationship to current memory theory are highlighted. Emphasis is focused on the impact of semantic memory on episodic odor recognition. In contrast to previous research suggesting that verbal/semantic factors play a negligible role in olfactory memory, the present review indicates that episodic odor information is mediated by factors that can be subsumed under the rubric of semantic memory. Specific odor knowledge, such as perceived familiarity and identifiability, is strongly and positively related to episodic odor memory performance. Age-related impairments in various olfactory and cognitive parameters and the potential detrimental effects in episodic odor memory are discussed. Finally, the issue of whether olfactory memory should be conceptualized as an independent process, or whether it shares characteristics with memory for verbal and visual information, is addressed. **Chem. Senses 22: 623–633, 1997.**

Introduction

Traditionally, memory research has been focused primarily on memory for information that is experienced by our visual and auditory sensory systems, and has largely ignored the olfactory sensory system. Little is yet known regarding whether olfactory memory follows the same principles as memory of information acquired through other sensory modalities. The main aims in the present overview are to discuss the available scientific knowledge on human long-term olfactory memory and to highlight its relationship to current memory theory. Because of the restricted knowledge in implicit odor memory (for review see Schab and Crowder, 1995), I here focus on explicit measures of odor memory. In so doing, the important role played by semantic memory in episodic recognition of common odors across the adult lifespan is emphasized.

Theories of memory

Much contemporary work has been devoted to the study of the organization of human memory. The idea that memory is composed of a series of interdependent brain systems has been contrasted with process-related accounts of how memory works. It is of interest to note that research focused on normal memory has tended to argue for a process-oriented view (e.g. Roediger, 1990; Blaxton, 1995; but see Tulving, 1993), whereas the study of abnormal memory has often been conceptualized in terms of a systems framework (Cohen and Squire, 1980; Tulving and Schacter, 1990; Gabrieli, 1995).

In the context of the relationship between awareness and memory, Graf and Schacter (1985) drew an important distinction between implicit and explicit memory tasks. In tasks tapping explicit memory (e.g. recall, recognition), test instructions are directed toward conscious recollection of a prior event or study episode. In contrast, in implicit memory tasks (e.g. perceptual identification, fragment completion, stem completion), no reference is given to a prior learning episode; subjects are not informed of the connection between the study and the test.

The explicit/implicit distinction is supported by evidence that amnesic patients show impairment in explicit tasks and relative preservation in various tasks assessing implicit memory (e.g. Graf and Schacter, 1985; Shimamura, 1986). Such findings, along with other evidence of dissociated explicit/implicit performance in normal adults (Tulving *et al.*, 1982) and in aging (Light and Singh, 1987; Parkin and Russo, 1990), have played an important role for views advocating the existence of distinct memory systems, or separate neural networks that mediate different forms of learning (Cohen and Squire, 1980; Tulving, 1985; Gabrieli, 1991, 1995).

Although it is still based on hypothetical constructs, the view that human memory is composed of five interrelated memory systems has been highly influential (Tulving, 1983, 1985, 1993; Tulving and Schacter, 1990; Nyberg and Tulving, 1996). According to this perspective, memory may be decomposed into:

1. *Procedural memory*, which is expressed through skilled behavioral and cognitive procedures.
2. *Perceptual representation system (*PRS) or *priming*, which is primarily concerned with improving identification of perceptual objects.
3. *Semantic memory*, which is concerned with acquisition and use of factual knowledge.
4. *Working memory*, which registers and retains incoming information in a highly accessible form, for a relatively short period of time.
5. *Episodic memory*, which requires conscious recollection of personally experienced events acquired in a particular place at a particular time.

According to proponents of systems theory, it is assumed that the above ordering of systems corresponds to their presumed developmental sequence in both a phylogenetic and an ontogenetical sense; procedural memory is conceived of as the earliest to develop, episodic memory the latest. The ordering also reflects the assumed relations among the systems: many operations of subsequently evolved systems are assumed to be dependent on and supported by the operations of earlier systems, whereas earlier systems can operate essentially independently of the later ones. Furthermore, Tulving (1993) has made certain assumptions about the relations between memory systems and states of awareness. To consciously recollect or remember something is a product of the episodic system. Feelings of familiarity or knowing are characteristic of retrieval from semantic memory, which is thus implicit in nature. Lack of awareness is characteristic of retrieval from the procedural and PRS systems. Working memory or primary memory gives rise to a fleeting awareness of recently experienced events.

Alternative theories opposed to the systems approach are those which emphasize process differences within a unitary memory system (e.g. Roediger, 1990; Blaxton, 1995). According to the process view, memory performance is influenced by the degree to which the type of processing engaged in at study is recapitulated at test (i.e. transfer-appropriate processing). Given that there is a mismatch between study and test, performance will drop. Jacoby (1983) proposed that two kinds of processes are involved in implicit and explicit memory: conceptually driven processes, which are concerned with stimulus meaning; and perceptual processes, which are concerned with stimulus format. The processing framework posits that dissociations occur (e.g. between explicit/implicit memory and normal/amnesic persons) on the basis of the degree to which the memory test involves perceptual and conceptual processes, irrespective of whether the test format is explicit or implicit.

In a broad sense, neither the process view nor the systems view can be rejected. Both perspectives are supported by a wealth of data, and there is also research that would seem to be at variance with both views. To be sure, it may be difficult, if not impossible, to conduct the critical experiment that would adequately discriminate between the two positions. To complicate matters further, it may also be that a certain perspective (e.g. one emphasizing processes) is feasible at a behavioral level, whereas another perspective (e.g. one emphasizing structures) makes more sense at a neurobiological level. Perhaps there is also room for interaction between these views. This is so because processes may not operate in a vacuum, but rather within particular structures. Likewise, a system deprived of processes would appear maladaptive.

The following sections highlight episodic and semantic components in olfactory processing, and the involvement of semantic memory in episodic odor memory will be discussed. Also, age-related differences in olfactory cognition and the impact of individual difference variables that are of importance in explaining age deficits in episodic odor memory performance will be addressed.

Semantic memory in olfaction

Tulving's (1972, 1993) distinction between episodic and semantic memory has proved to be a useful tool in understanding olfactory cognition. The two main tasks used in the study of odor memory are odor recognition and odor identification. The former task is related to episodic memory, whereas the latter taps semantic memory functions.

Semantic memory refers to a subject's general knowledge or experience with a specific odorant, and is exemplified in odor identification and familiarity ratings. The concept of olfactory knowledge may be viewed as a continuum of informational specificity (Schab, 1991). At the most primitive level, olfactory experiences are subject to ratings of hedonic qualities (e.g. I like this smell) or of familiarity (e.g. I have smelled this before). At the next higher level, the smeller is able to describe the odor in general and adjective terms (e.g. spicy and dark). The next step involves even more specific knowledge but without being able to produce the odor's name (e.g. Christmas attribute), which is followed by the highest degree of informational specificity where the subject is able to retrieve the name of the odor (e.g. cloves).

Odor familiarity

As noted, one aspect of semantic knowledge of odors is exemplified by the perceived familiarity of the olfactory experience. In contrast to identification measures, this parameter makes no demand of explicit verbal characterizations. Typically, familiarity is assessed using scales in which subjects are instructed to rate the perceived familiarity (from low to high) of a given odor.

Both familiarity and identification tap reservoirs of prior knowledge about odors (de Wijk *et al.*, 1995). However, whereas the identification task requires the subject to give a verbal descriptor of the odor as a means of assessing the presence of semantic processing, familiarity ratings only require the smeller to mark the corresponding perceived familiarity. In this sense, level of familiarity may be regarded as a continuum covering the subject's implicit level of odor knowledge. A low familiarity rating may reflect an extremely vague perception, with no distinct semantic cues elicited by the olfactory experience. A medium rating may involve moderately meaningful associations, whereas a high familiarity rating presumably reflects the experience of having access to more specific knowledge about the odor. Occasionally, a high familiarity rating may simply reflect knowledge of the odor name, which would make this measure equivalent to identification. This is presumably true in some cases, but considering the large number of tip-of-the-nose states for olfactory stimuli, an item rated as highly familiar may truly reflect access to a more general or idiosyncratic knowledge of the odor, such as belonging to a specific food category (e.g. the spice you find in pizzas), or referred to as an odor that 'I felt in Paris in that specific corner'.

Odor identification

It is widely accepted that naming odors spontaneously is a difficult task. In normal subjects, it is common to smell an odor and to recognize it as familiar and belonging to a general class or category, but still being unable to produce a specific label. Lawless and Engen (1977) described this as the 'tip-of-the-nose' phenomenon; that is, as the olfactory analog to the tip-of-the-tongue state (Brown and McNeill, 1966; Brown, 1991). However, in contrast to the latter, persons in the tip-of-the-nose state typically cannot answer any questions about the name of the odor, such as the initial letter, the number of syllables, or the general configuration of the word. Subjects can, however, answer questions about the odor's quality, such as its taxonomic category, or say something about objects associated with it (Lawless and Engen, 1977).

Although humans in general are sensitive in detecting odors, and can discriminate among hundreds of odors in side-by-side comparisons (Doty, 1992), our ability to identify an odor verbally is extremely limited. Reviews indicate that unaided free identification of odors by young laypersons varies between 22 and 57%, with set sizes of 7–80 items (e.g. Cain, 1979; Richardson and Zucco, 1989; Chobor, 1992). Even everyday odors, which are highly overlearned (e.g. chocolate), may prove extremely difficult to name.

Odor identification abilities are also assessed through multiple-choice test procedures (e.g. Doty *et al.*, 1984a, 1989). In these tests, response alternatives are presented verbally, one target in conjunction with a number of foils. Not surprisingly, subjects perform better in multiple-choice tasks than in free odor identification. This superiority is presumably related to lessened cognitive demands. The provision of label alternatives reduces the effort an individual has to invest in searching for an appropriate label, and thus a multiple-choice test may be regarded as more supportive. However, it is important to note that identification performance will vary as a function of foil selection. Engen (1987) showed that with highly dissimilar foils (e.g. pizza, turpentine, clove for the target grape), performance reached 93% correct identification. However, if the foils were selected as highly similar to the target (e.g. melon, strawberry, plum), identification dropped to ~50% correct. This outcome suggests that poor odor identification may stem from problems in selecting the correct label from a number of related alternative labels.

As stated above, young healthy subjects can typically name about half of a set of odors with precision in free identification. For the other half, subjects may give labels that are reasonably good approximations to the target label (e.g. lemon for orange) or surprisingly poor labels (petrol for vanilla), or simply fail to give any verbal description of the odor. Although it may seem like a minor error to call the odor of orange for lemon, such an error, if presented with an orange visually, would seem large indeed (Schab and Cain, 1991).

Two major factors have been proposed to account for the difficulty in retrieving the association between an odor and its lexical representation. In an experiment performed by Cain (1979), it was shown that subjects' identification performance was highly sensitive to feedback of the odor names. Across three trials perfomance improved from 45% to ~90%. This outcome suggests that, given a supportive environment, subjects are able to efficiently utilize their semantic knowledge, and that proficiency in odor identification is highly modifiable. Engen (1987) and Schab and Crowder (1995b) proposed that an inherently weak connection between language and olfactory processes causes the temporary blockage of retrieval of well-learned olfactory information. Findings of fast re-learning once a veridical label is offered, and that people have little difficulty in retrieving the names of corresponding objects to odors, suggest a weakness specifically related to odor–name associations.

A second factor that may explain the impoverished ability in odor identification has been proposed by Cain and his colleagues (Cain, 1979; Schab and Cain, 1991; Cain and Potts, 1996). These investigators argued that misidentification may be related to misperception. Specifically, the claim is that odor identification is heavily dependent upon odor discrimination ability. Thus, errors in identification may arise from failures in discrimination. For example, if a person calls the odor of orange, lemon, was the odor really perceived as lemon? The point here is that poor identification could have a perceptual origin. This is an important point, because most studies that have focused on odor identification have neglected the potential influence of the discriminatory dimension in odor perception, and its relationship with performance in identification.

Episodic memory in olfaction

In general, episodic memory is assessed by asking a subject to retrieve items from a previous presentation of a study list (e.g. words, objects, odors). In a typical odor recognition memory experiment, the subject is exposed (with incidental or intentional encoding instructions) to a number of odors and later asked to recognize the target odors in the context of new odors (distractors).

Earlier work on olfactory memory indicated that odors that were successfully encoded showed relatively slow forgetting, possibly because of a negligible impact of retroactive interference (e.g. Engen and Ross, 1973; Lawless and Cain, 1975; Engen, 1987). Based on the rather flat forgetting function, it was assumed that odors are encoded as unitary perceptual events. Typical findings in these studies were imperfect initial encoding, little subsequent forgetting, and no effects of familiarity and identifiability. Engen and Ross (1973) showed that subjects recognized only 75% of the studied odors immediately. However, performance dropped only to 65% after 1 month and remained above chance even after 1 year. A similarly flat forgetting function was obtained by Lawless and Cain (1975), who reported an immediate recognition performance of 85% which declined to 75% over a span of 28 days. Over a 6 month period, Murphy *et al.* (1991) reported that odor memory declined only slightly in a group of young adults, but this study also indicated that the retention for faces and symbols remained fairly constant over the same time period.

However, more recent data are at variance with the view of odors as impervious to forgetting, in showing a significant loss of olfactory information across time (Walk and Johns, 1984; Cain and Murphy, 1987; Perkins and McLaughlin Cook, 1990). Also, significant forgetting has been shown to occur with verbal suppression techniques, which suggests that odors may not be represented as holistic, unitary percepts in memory which are resistant to interference and forgetting (Perkins and McLaughlin Cook, 1990). Other work also questions the earlier view of only minimal losses of olfactory information across time, demonstrating that odor memory is not resistant to decay. For example, Larsson and Bäckman (1993, 1997a) reported a significant drop in recognition performance over a 48 h interval in both young and older subjects. An important reason as to why common odors are prone to forgetting may be that this type of information involves episodic and semantic features in addition to sensory features (Baddeley, 1990; Perkins and McLaughlin Cook, 1990; Stevens *et al.*, 1990).

It is also of interest to highlight the popular notion that odor memory is 'better' than memory for other types of information. It may be of interest to discuss the meaning of this notion. For instance, comparing odor recognition performance with recognition scores for faces (i.e. *d* scores), it is obvious that odor recognition generally is substantially poorer relative to memory for visual and verbal information (Bäckman, 1991; Larsson and Bäckman, 1993; Olofsson and Bäckman, 1996), a difference which tends to increase with increasing age (Murphy *et al.*, 1991; Larsson and Bäckman, 1997b). This suggests that, at least from a quantitative perspective, retention of odors is poorer than retention of faces. Perhaps people's subjective experience of odors evoking strong memories concern recollection of single, distinct odors, or relate to odors that may trigger memories of unique events of an emotional nature.

The relationship between olfactory knowledge and episodic odor recognition

It is of theoretical interest to investigate the role of verbal/semantic mediation in human olfactory memory. If olfactory memory is not dependent on linguistic or verbal factors, then olfactory processing would be fundamentally different from the cognitive processing carried out in other modalities. A number of studies focusing on verbal and visual materials have highlighted the role of semantic memory for proficient episodic remembering (Paivio, 1986; Bäckman *et al.*, 1990; Tulving, 1993). For example, sizeable performance increments in episodic memory occur in tasks where the information-to-be-remembered is semantically elaborated (Craik and Lockhart, 1972; Zelinski *et al.*, 1993) or organizable (Gollin and Sharps, 1988; Bäckman and Larsson, 1992), or when task-relevant knowledge is available (Bartlett, 1977; Bäckman, 1991). Related to this, research has indicated that performance in tasks that may be subsumed under the concept of semantic memory, such as vocabulary and verbal fluency, are important predictors of episodic memory for verbal and visual materials in both young and older subjects (Craik *et al.*, 1987; Hultsch *et al.*, 1990).

As noted, the dominant assumption made in earlier work has been that odors are encoded perceptually as relative featureless stimuli and that semantic or verbal factors play little or no role in episodic odor recognition (Engen and Ross, 1973; Lawless and Cain, 1975; Larjola and Von Wright, 1976; Lawless and Engen, 1977). Engen and Ross (1973) provided subjects with correct labels of the odors during encoding and found no evidence of better subsequent recognition performance when compared with odors presented without labels. Likewise, Lawless and Cain (1975) instructed their subjects to name odor stimuli with personally meaningful descriptors at study, and found no benefit of this instruction in recognition memory. Taken together, these experiments suggest that the representations of odors in memory do not involve semantic information.

However, this view has been challenged in more recent work showing that specific odor knowledge is positively related to episodic odor memory performance. For example, it has been demonstrated that memory for familiar and identifiable odors is better than memory for unfamiliar and less identifiable odors (Lyman and McDaniel, 1990; Schab and Crowder, 1995a). Likewise, Rabin and Cain (1984) and Larsson and Bäckman (1997a) demonstrated a strong relationship between a subject's specific knowledge about an odor and the ability to recognize it in a subsequent recognition memory task. Specifically, these authors found that rated familiarity and label quality were positively related to recognition performance. Memory performance increased as a function of the quality of the label given for the odorants; that is, memory was poorest for odors to which far misses had been generated, slightly better for identifications defined as near misses and highest for odors that had been correctly named.

Further evidence of the presence of a semantic code in episodic odor recognition was provided by Walk and Johns (1984). Specifically, these researchers reported that interference from interpolated events may occur in odor memory. The results indicated that recognition performance was poorest when subjects free associated to an additional odorant during the retention interval, whereas it was highest when they free associated to the name of the target odorant during the retention interval. In another study, the effects of visual suppression, verbal suppression and combined suppression were examined in retention of olfactory information (Perkins and Cook, 1990). Overall, the results indicated that performance was lower in the suppression groups than in the control groups. The verbal and the combined visual-plus-verbal suppressions were most detrimental to recognition performance, whereas visual suppression showed no effect on memory relative to the control condition. However, more recent work has indicated that visual suppression does impair olfactory recognition performance, although it is not clear to which extent visual processing is contaminated by verbalization (Annett *et al.*, 1995; Annett and Leslie, 1996).

Two important studies by Lyman and McDaniel (1986, 1990) provided evidence of the role of semantic activities at encoding in odor recognition performance. In their first study, subjects were instructed to generate (i) a visual image, (ii) a name and (iii) a life episode while smelling a set of common odors. As compared with the control condition, in which subjects were instructed to simply remember the presented odors, odorants that were named and associated with a significant life episode were shown to be best remembered after a 7 day retention period. In a follow-up study (Lyman and McDaniel, 1990), a similar pattern of results emerged. Here, odors were encoded with (i) a visual representation (photographs), (ii) odor names or (iii) both. As compared with a control condition, performance after a 7 day interval was higher for elaborated odors, and combined visual and verbal elaboration produced the highest recognition performance. It is of interest to note that there is some evidence that semantic memory measures assessing retrieval of general knowledge, such as vocabulary and verbal fluency (Craik *et al.*, 1987; Hultsch *et al.*, 1990) and educational background, may be of minor importance in predicting episodic memory for olfactory information (Larsson and Bäckman, 1997a). This outcome is at variance with available evidence from memory research using verbal and visual stimuli (e.g. Inouye *et al.*, 1993), and suggests that episodic odor memory may partly operate on its own premisses.

Although further research is needed, available evidence suggest that recognition memory for common odors is sensitive to semantic memory manipulations (Lyman and McDaniel, 1986, 1990; Larsson and Bäckman, 1993), which is in agreement with knowledge on visual and verbal memory (Craik and Lockhart, 1972; Bäckman, 1991). Furthermore, specific odor knowledge, such as perceived familiarity and odor naming, is positively related to episodic odor memory. However, and in contrast to the bulk of research focusing on verbal and visual information, olfactory memory do not seem to be related to educational background and to proficiency in semantic memory measures assessing more general aspects of knowledge (Larsson and Bäckman, 1997a).

Explaining age-related deficits in odor memory

Age-related deficits in episodic memory for various types of information are well established (for reviews see Light, 1991; Kausler, 1994). It has been proposed that this age deterioration is related to older adults having fewer processing resources available in order to learn and retrieve new information (for a review see Craik and Jennings, 1992). A number of hypothetical factors related to the concept of processing resources have been identified, such as speed of processing and a reduced working-memory capacity (Hultsch *et al.*, 1990; Salthouse and Meinz, 1995), and these factors have also been shown to account for the age-related variation in episodic memory performance. The relative impact of these factors on olfactory memory is still an unexplored issue. However, considering that the olfactory system processes information more slowly than other sensory modalities (Laing and MacLeod, 1992; Herz and Engen, 1996), this slowness, in combination with age-related cognitive slowing (Salthouse and Lichty, 1985; Bryan and Luszcz, 1996), may be one reason why age differences have been proven to be exacerbated in olfactory memory relative other types of information (Murphy *et al.*, 1991; Larsson and Bäckman, 1997b).

Age-related deficits in olfactory abilities, such as odor recognition (Cain and Murphy, 1987; Murphy *et al.*, 1991) and odor identification (Schemper *et al.*, 1981; Doty *et al.*, 1984b; Wood and Harkins, 1987), have been demonstrated. One issue of interest has been to explore the extent to which these decrements are related to losses in sensory acuity (e.g. Murphy *et al.*, 1985; Van Toller *et al.*, 1985; Cain and Gent, 1991) or to cognitive changes with increasing age. Some recent research suggests that sensory deficits alone cannot explain impairments in odor recognition memory and odor identification abilities among older subjects (Murphy *et al.*, 1991; Larsson and Bäckman, 1993, 1997a).

One parameter that relates to olfactory sensitivity is the perceived intensity of olfactory stimuli. Intensity ratings for suprathreshold odors have proved to be lower in older subjects than in younger ones (Stevens and Cain, 1986, 1987), which in turn may have adverse effects on odor memory performance. One way of evaluating the role of threshold sensitivity for age differences in odor recognition is to vary the intensity degree of odorous stimuli. That is, is it possible for older adults to compensate for their deficits in episodic odor recognition and odor identification by increasing the intensity levels in the olfactory information? If so, then observed age deficits may be attributed to losses in suprathreshold strength (Stevens and Cain, 1986, 1987). This issue was addressed in an experiment by Stevens *et al.* (1990). The results indicated that retention of odors was unrelated to the degree of intensity in both young and older adults. With regard to odor identification, intensity degree was weakly related to performance, but most important, there was no interactive relationship with age. The role of suprathreshold strength and intensity perception on odor memory and aging is a topic that needs further exploration. However, available knowledge suggests that intensity is of minor importance in explaining age-related deficits in odor memory (Stevens *et al.*, 1990).

A number of cross-sectional studies have reported that women perform better in odor recognition (Lehrner, 1993) and odor identification (Doty *et al.*, 1984b) tasks than do men. In the first published longitudinal study assessing olfaction in adulthood, Ship *et al.* (1996) replicated and extended earlier cross-sectional results by showing that the pattern of deterioration in odor identification with age is similar in males and females, but delayed by ~20 years in women. More specifically, the results indicated that males experience a more precipitous and earlier decline in smell identification than do women. Males declined significantly in identification performance by the age of 55 years, whereas this decrement was not evident in women until the age of 75 years. This finding suggests that the pattern of smell deterioration varies as a function of gender. These results were obtained using the UPSIT test, which has been identified as a reliable test of smell function, with high test–retest reliability coefficients and a strong correlation to odor detection thresholds (Doty *et al.*, 1984b, 1985). With reference to the reliable relationship between sensory acuity and performance in the UPSIT test, it is of interest to note that other recent work suggests that healthy women up to 80 years of age show only slight changes in sensory functioning relative to younger females (Larsson and Bäckman, 1993, 1997a).

Two studies by Larsson and Bäckman (1993, 1997a) indicated that the crucial factor for odor recognition performance in general, and for age-related differences in odor recognition (20–80 years of age) in particular, is the subject's specific semantic knowledge of the odors presented. First, the degree to which an odor connects with experience, as indexed by rated familiarity, was positively related to hit rate performance at both immediate and delayed recognition (48 h) across the adult lifespan. Memory performance increased as a function of increasing familiarity, which is consistent with previous findings (Rabin and Cain, 1984; Murphy *et al.*, 1991). Second, the quality of the given odor name was associated with both immediate and delayed recognition memory performance. Regression analyses indicated that chronological age and odor naming were the most potent variables in predicting episodic odor memory. Statistical control for odor naming resulted in the effect of age disappearing, indicating the pivotal role of accessibility of odor names for succesful episodic odor recognition and for age-related differences in episodic odor recognition. Knowing that age deficits in odor naming underlies the age-related impairment in odor recog- nition, it is of interest to consider potential explanations for older adults' problems in naming odors. Three different explanations of this deficit may be postulated. First, the decrement may have a perceptual origin; that is, odors may be misnamed because of a misperception (e.g. Cain and Potts, 1996). Second, older persons' semantic knowledge of a given odor may be degraded (e.g. Salmon *et al.*, 1992). In this regard, failure to name the odor of blackcurrant is due to an erosion of the specific semantic attributes that determines the concept of blackcurrant. Third, age deficits in odor naming may be related to age-related impairmants in lexical access. Subjects may have access to the semantic knowledge of an odor, although their ability to retrieve the specific name is impaired (Larsson and Bäckman, 1997a). These are topics that need to be further explored in future research.

To summarize, available evidence suggests that age deficits in odor memory are to a large extent related to age-related impairments in cognitive functioning. Further work is needed in order to evaluate the potential impact of age-related reductions in processing resources on episodic odor memory. However, available evidence suggests that the ability to name odors appears to be an extremely important factor not only for episodic recognition of odors in general, but also for age-related deficits in odor recognition. The source of the age deficit in odor identification remains an open question. To date, proposed explanations for the impairment include perceptual/discriminative deficits, a degraded olfactory knowledge base and/or failures in lexical access.

Concluding remarks and future directions

The main aim of the present review has been to highlight the role played by semantic memory in episodic odor recognition. It is important to note that the results discussed above are restricted to recognition memory for common odors, which likely represents overlearned information in the individual's network of semantic knowledge. An important issue to address in future research therefore concerns memory for unfamiliar odors where the influence of semantic and verbal mediation is minimized.

The fact that older adults have greater difficulties in accessing odor names, which in turn underlie the age-related deterioration in episodic odor memory, implicitly implies that age differences may be overcome in tasks with minimal involvement of semantic memory functions (i.e. memory for unfamiliar odors). However, this is not to say that age differences would be non-existent in recognition memory for uncommon odors. Other age-sensitive factors (e.g. working memory, odor discrimination) that perhaps play a lesser role in memory for common odors may increase in importance when the lexical demands are low.

As noted above, one important question in olfactory research is whether this sensory system should be conceptualized as similar to or different from our other sensory modalities. The present overview suggests that olfactory memory may be influenced in a similar fashion, from activation of prior knowledge, as is memory for visual and verbal information. However, in contrast to the well established influence of educational background and general lexical retrieval on episodic memory involving verbal and visual information, these factors appear to be unrelated to retention of olfactory information. This outcome suggests that memory for olfactory information may operate according to different principles compared with other types of information. Therefore, it would be of great interest to study further the relative impact of various individual-difference factors known to be related to olfactory performance (e.g. odor discrimination, odor intensity), and factors known to have an influence on episodic memory in general (e.g. cognitive speed, working memory) for proficient odor recognition. In this way, it will be possible to obtain a more complete picture of whether odor memory should be conceptualized as a phenomenon working on its own premisses or one that largely resembles memory for episodic information acquired through our other sensory modalities.

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Received on May 7, 1997; accepted on August 12, 1997