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Anomalies in Cognition: Olfactory Memory

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The two experiments presented in this paper examine the effects of strategies and interference tasks on odor recognition. In the first experiment (an extension of Lyman and McDaniel's study from 1986), participants were asked to smell 30 odors and to perform different elaborative tasks for each of them such as: (1) providing a name or a short definition; (2) creating an image; (3) describing a specific life episode; (4) simply smelling the odors. Results showed no effect of encoding tasks on the correct recognition of odors.
In the second experiment, participants were exposed to either 15 olfactory stimuli, 15 visual stimuli (photographs of human faces), or 15 acoustic stimuli (environmental sounds). In the four sessions of the experiment, they had to recognize the stimuli whether in a no-interference condition, or in an intramodality, or in two intermodalities interfering conditions. Consistently with the literature, interference affects recognition for visual and acoustic material but has no effect on odor recognition.
The results of both experiments and some other anomalies in olfactory memory are discussed and tentatively integrated into a single model. The main assumption is that memory for odors represents a unique and separate memory system.

Keywords: oder memory, consciousness, strategies and interferences

Introduction

Whether olfactory memory represents a separate and unique memory system, with different functional characteristics compared to the other sensory modalities, is an open issue (see e. g., Engen, 1991; Herz & Engen, 1996; Richardson & Zucco, 1989; Schab, 1991). Evidence to support this hypothesis is the following:

- Odor recognition memory is only slightly influenced by the length of retention intervals. This was observed for short intervals, for example, a few seconds and minutes (Bromley & Doty, 1996; Engen & Ross, 1973; Jehl, Royet & Holley, 1994; Jones, Moskowitz & Butters, 1975) as well as for longer retention periods such as a week (Lawless & Cain, 1975; Rabin & Cain, 1984; Wood & Harkins, 1987; Zucco, 1983), a month (Lawless & Cain, 1975), four months (Lawless, 1978), and over a year (Engen & Ross, 1973; Goldman & Seamon, 1992). Usually the forgetting curve resulting from these experiments is relatively flat, unlike for verbal and visual material (see Ebbinghaus's seminal experiments, 1885; and Shepard, 1967).
- Olfactory memory presents a relatively low initial acquisition level compared to visual and verbal material. This led Engen (1982, 1991) to assume that odors are represented in memory as unitary and distinctive events with little attribute redundancy. As evidence for this, Lawless (1978) found that common, complex odors were encoded and remembered as well as simple chemicals and abstract meaningless geometrical shapes. According to Lawless, odors are relatively featureless stimuli, which means that immediate recognition memory for odors is poor compared to visual and verbal stimuli, the latter being richer in accessible features. In Underwood's (1969) memory model, odors are

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stored by means of relatively inefficient forms of mnemonic coding (see Richardson & Zucco, 1989). Also, Schab, (1991) noted that "such stimuli, once encoded are characterized by a slower rate of forgetting, because fewer features per stimulus means less interference from stimuli with the same or similar features" (p. 248).

- Odor memory is very resistant to retroactive interference, i. e., to forgetting produced by subsequent learning experiences (see Lawless & Engen, 1977), while strong effects of proactive interference are observed (Engen, 1987; Lawless & Engen, 1977). Generally speaking, the absence of a retroactive interference effect could explain the endurance of olfactory traces over time (see also Herz & Engen, 1996). Also, according to Schab (1991) odors acquired in experimental conditions and environmental odors are processed differently, and the second cannot interfere with the first. This hypothesis, however, needs to be experimentally verified.
- Odor memory seems to be unaffected by the familiarity of the substances used, as well as by the pleasantness of the substance (Engen & Ross, 1973; Lawless & Cain, 1975). Furthermore, giving odors a meaningful label has no effect on the subsequent recognition of the odors (Lawless & Cain, 1975). Indeed, the relationship between odors and words seems to be very weak: Subjects show difficulties in the correct identification of the odors (Cain, 1979, 1982; Engen, 1991; Engen & Pfaffmann, 1960; Sumner, 1962; Zucco & Aiello, 1996); verbal rehearsal and verbal interference tasks do not affect their recognition (Gabassi & Zanuttini, 1983; Engen, Kuisma & Eimas, 1973); the right hemisphere seems to be involved in the elaboration of odors (Abhram & Mathai, 1983; Zatorre, Jones-Gotman, Evans, & Meyer, 1992; Zucco & Tressoldi, 1989).
- No differences emerge in recognition tasks for odor stimuli learned intentionally or incidentally (see Engen & Ross, 1973, for a seminal paper).

The effect of strategies and interference tasks on odor recognition have been examined less thoroughly in the literature. The two experiments presented here aim to address these issues.

Strategies and Odor Memory

Few studies have been carried out on the effects of strategies on odor recognition. Among these, Walk and Johns (1984) examined the effects of different instructions on short-term odor memory. Four groups of subjects were asked to perform one of the following tasks, during the retention interval between odor acquisition and recognition: (1) to make free associations with the target odor, (2) to make free associations with the name of a new distractor odor, (3) to smell a new distractor odor and to make verbal associations to it, and (4) control condition. Authors found that recognition performance was best when participants made free associations with the target odor during the retention interval. Walk and Johns assume that memory for odors and memory for stimuli in other modalities may share similarities.

In an another study, Rabin and Cain (1984) asked their subjects to give a label to each substance of the stimulus set. In the following recognition test (one week later), authors found that naming the stimulus correctly (during both acquisition and retrieval) was positively correlated with odor memory; other authors, however, failed in finding any memory facilitation by the use of verbal labels or rehearsal (Engen & Ross, 1973; Gabassi & Zanuttini, 1983; Lawless & Engen, 1975).

A more direct manipulation of elaborative processing was carried out by Lyman and McDaniel (1986). Their study is examined in more detail here, since the first experiment presented below is a replication thereof.

Authors asked four groups of subjects to smell 30 odors and to perform one of the following tasks for each of them: (1) to provide a name and a short definition; (2) to create an image; (3) to describe a specific life episode; (4) simply to smell the odors for a subsequent recognition test.

One week later subjects were asked to recognize the 30 odors out of a set of 60. Participants who had associated either names or personal episodes to odors gave the lowest false alarm (FA) scores; control and visual-imagery groups gave the highest FA scores, which were significantly different from those of the two former groups. Episode vs naming and control vs visual-imagery comparisons did not differ significantly.

Hit scores, too, did not differ significantly among conditions. Nevertheless, the authors maintained that elaborative processing, such as naming odors or providing life episodes for them, lead to the best recognition performance (p. 753, 760). However, such a statement is a little puzzling; in fact, their results would suggest that strategies were effective only in *rejecting* items that did not belong to the acquisition list.

Further, the authors observed that the "naming" condition produced the best performance, while no differences emerged between "control" and "imagery" groups. These results are at odds with the literature: It is

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well known that visual codes give rise to a better memory performance than do verbal codes (Paivio, 1986)—and also that to give an odor a name is a very difficult cognitive task (Engen, 1991; Richardson & Zucco, 1989) since the odor-name relationship is very weak (Herz & Engen, 1996; Lawless & Cain, 1975; Zucco & Tressoldi, 1989)

In a second paper, Lyman and McDaniel (1990) observed that the use of strategies such as processing a picture or a name of the source of an odor was effective in odor memory (1st experiment). One group of subjects were presented the photographs of the referent source for 30 odors (in addition to the odors themselves); a second group was presented with the names of the 30 odors (in addition to the odors themselves); while a third group was presented both the names *and* the photographs (in addition to the odors themselves). A final two groups (name only and odor only control groups) were presented only the names of the odors or the 30 odors. Analyses indicated that both visual and verbal elaborations improved recognition. However, results differ from those of the 1986 paper, where the use of imagery played no role in the recognition of odors. Further, the significant effect on hit scores was very small in its magnitude. In the second experiment of the same paper Lyman and McDaniel instructed a first group of subject to imagine the scent of 20 stimuli presented verbally (e. g., The odor of the word "banana"), while a second group of subjects was instructed to conjure up 20 images of the same names. At recognition, subjects were exposed to 40 odors and to 40 pictures and were required to distinguish which of them corresponded to the words they had seen previously. Subjects who had imaged olfactory information of the words and recognized odors performed better than subjects who had imaged olfactory information and recognized pictures. A similar pattern was observed for pictures. However, while significant differences among conditions were found for *d′* and FA scores, the results on hits showed no facilitation by olfactory imagery on recognition of odors and by visual imagery on recognition of pictures. Herz and Engen (1996), reviewing this paper, pointed out that "The imagery results were therefore dependent on differences in false alarm rates as a function of different encoding strategies, and, as such, it is questionable how meaningful they are" (p. 305). Thus, the role of strategies on odor memory is far from being understood.

The first experiment presented here is a replication and extension of Lyman and McDaniel's first study (simpler in its experimental structure than the second). Any methodological differences are described below. No effects of elaborative encoding activities on odor memory are expected.

Experiment 1

Method

Participants

Forty-eight university students ranging in age from 20 to 30 years participated in the experiment (M = 24.7 years). They were randomly assigned to one of the following conditions: visual-imagery, label-plus-definition, life-episode, and control. Both sexes were represented (7 males and 5 females per condition). None of them had any impairment of the olfactory system.

Material

Sixty olfactory stimuli contained in small glasses and fitted with rubber plugs were used. The plugs were connected to a cotton swab wrapped at the end of a stick. Test tubes were covered with white paper to prevent participants from having visual cues. Substances were almost all pleasant and natural, and were replaced every 48 hours, so that concentration of the odors was kept under control. Thirty stimuli were used in the odor-acquisition phase and the other 30 as distractors for the recognition test. Odors were almost all the same as those used by Lyman and McDaniel (1986), for example, almond, Brut after-shave, clay, lemon, pipe tobacco, soap, vanilla, Vicks.

Procedure

Participants were individually administered the tasks. They were informed that they had to smell 30 different odors, one after the other, and then, a week later, they would have had to recognize such stimuli among a set of 60. Participants were asked to smell each odor for about 15 seconds followed by 20 seconds during which they had to perform the encoding tasks, that is:

a) *Visual imagery condition:* Participants had to create an image of the source of the odor. For instance, if they thought they were smelling beer, they may try to create an image of a glass (or a can) of beer in their mind.
b) *Label-plus-definition condition:* Participants were asked to think of a name and a short definition for the odor that they were smelling. If they were not able to give a name to the odor, they were asked to try and name a close associate.

c) *Life-episode-condition:* Participants were asked to try to remember a specific episode of their life related to the odor that they were smelling.
d) Participants in the *control group* had only to smell each odor. All associations made by participants in the three experimental groups were tape-recorded; subjects were strongly recommended to try to follow their task demands.

One week later, subjects were administered the recognition test. They were presented, in random order, 60 odors (30 target and 30 distractors), and they were asked to try to recognize those presented in the acquisition test by circling the words "new" or "old" on a booklet. Both in the acquisition phase and here subjects were instructed to close their eyes while smelling each odor.

Furthermore, subjects in the three experimental groups were asked to tell, what association they made the week before, for each odor recognized.

The experiment took place in a well-ventilated room; the order of stimuli was randomized for each subject. Responses were scored for accuracy.

Results

On the data, hit and false alarm rates and *d′* scores were considered. Table 1 shows the results as a function of experimental conditions. For each of these measures a one-way between-subjects analysis of variance (ANOVA) was carried out. The single factor "encoding task" (control vs visual-imagery vs label-plus-definition vs life-episode) reached a significant level for *d′*: $F(3, 44) = 5.14$, $p < .004$. Pair-wise post-hoc comparison using Tukey test shows the following significant effects: life-episode vs control ($p < .01$) and life-episode vs label-plus-definition ($p < .01$); the other comparisons were not significant. The ANOVA on hits was not significant ($F = 2.06$). The ANOVA on false alarm reached significance: $F(3, 44) = 3.10$, $p < .04$; but a Tukey pairwise post-hoc comparison did not show any significant effect.

A further analysis was carried out on the correct recognition of the odors for which participants were able to recall also the associations made for them at acquisition (i. e., the words, or the images, or the episodes).

On hit scores, a one-way between-subjects ANOVA was performed. The analysis was not significant ($F = .528$). Mean proportion of hits, according to the experimental conditions, were as follow: life-episode = .50; visual-imagery = .45; label-plus-definition = .42

Finally, the proportions of correctly recognized odors (i. e., life-episode = .50; visual imagery = .55; label-plus-definition = .58) vs the proportions of correctly recognized odors plus the correct associations (see above), were analyzed, by *t*-test, for each experimental group. None of these comparisons was significant.

Table 1
Mean scores of *d′*, Hits and False Alarm as a function of encoding conditions. (Lyman and McDaniel's study scores, are shown in brackets).

	Encoding Condition			
	Control	Imagery	Episode	Label
d′ scores	1.32	1.49	1.82	1.32
	(0.45)	(0.68)	(1.07)	(1.21)
Hits	0.82	0.79	0.83	0.75
	(0.64)	(0.68)	(0.69)	(0.69)
False Alarm	0.37	0.26	0.22	0.27
	(0.44)	(0.39)	(0.28)	(0.24)

Discussion

The main result of the first experiment is that it fails to show any crucial effect on recognition of odors by previous elaborative activities. This is particularly evident when considering the results on hit rates: Subjects, in fact, did not differ in their ability to recognize odors, despite the use of different encoding strategies. The analyses performed on the correctly recognized odors plus the correct associations provide further support.

The first indicates that no strategy was more effective than another (proportion of hits were in fact almost the same for all the three experimental groups), while the second suggests that the level of accuracy in recognizing odors is independent of the adoption of any strategy. No differences indeed come out from intragroup comparisons using *t*-test. Plausibly, if one is able to recognize a stimulus, but fails to recall the strategy used to promote its recognition, this means that such a stimulus was recognized *per se* (i. e., because of its own characteristics) rather than on the basis of elaborative processes. However, as suggested by one of the reviewers, it would be interesting to see if the positive effect of encoding strategies on recognition memory is related in the verbal and visual domains to good memory for the elaborations.

Both analyses were, then, crucial in testing Lyman and McDaniel's assumptions and suggest that strategies are not effective cues for recognition of odors.

Finally, a general *d′* significant effect was observed; but unlike Lyman and McDaniel's experiment, post-hoc comparisons here yield better performances for the life-episode and imagery groups than for the label-plus-definition group. Thus, these data seem to be consistent with those reported in the literature and discussed above, namely, the weak odors-words link and the efficacy of visual codes on memory. Moreover, analyses on FA have shown a general significant effect, but—at odds with the two authors—post-hoc comparisons failed to find significant differences among conditions.

In my opinion, only if correct recognitions or hit scores were to lead to clear differences among groups would then unquestionable effects of encoding strategies on odor recognition be actually demonstrated. Differences in FA and d' are not sufficient and meaningful conditions (FA is just a measure of the ability to reject items that do not belong to the acquisition list, and d' is a general measure of the accuracy and sensitivity in the discrimination among old and new items).

Interference and Odor Memory

Studies on the effects of interference tasks on odor memory are sparse. Furthermore, the results reported are quite unclear, so that the issue of interference in odor memory is still open.

Perkins and McLaughlin Cook (1990) and more recently Annett, McLaughlin Cook, and Leslie (1995) investigated whether memory for odors could be affected by concomitant interference tasks (see Baddeley, 1986). The rationale of the two studies was the following: If memory for odors represents a unique and separate memory system, then interference tasks should not affect the recognition of odors, whereas if olfactory memory *is* a part of a more general memory system, they should have that effect.

Perkins and McLaughlin Cook (1990) asked their subjects to smell 15 odors while performing one of the following tasks: (1) rehearsing some digits (verbal suppression condition); (2) performing a visual game (visual suppression condition); (3) both (verbal + visual conditions), and (4) simply smelling the odors for the subsequent recognition and recall tasks (control condition).

At immediate recognition (10 minutes later) the authors found that only tasks involving verbal suppression interfered with odor recognition; at delayed recognition, interference was observed also for the visual suppression task. Annet et al. (1995), using the same method with a few changes (e. g., a more complex visual task), obtained different results than Perkins and McLaughlin. Particularly, at immediate recognition the three experimental groups did not differ significantly from each other. In both studies, however, the level of recognition and recall scores was very low. Moreover, some aspects of the two studies are a little puzzling, e. g., in contrast to the literature the immediate and delayed recognition scores differed significantly (first experiment); and it is not clear why the authors used a recall procedure, this being just a measure of odor-name memory.

Thus, clear effects of interference on odor recognition were far from being demonstrated.

The effects of interference in short-term odor memory were found in the study by Walk and Johns (1984) quoted above. These authors observed that making associations to an additional distractor odor during retention interval led to the lowest recognition performance.

Lawless and Engen (1977), on the other hand, found clear effects of proactive, but not retroactive interference. Two groups of participants were required to learn one set or two sets of 12 pictures associated with a single set of 12 odors. In the first session they had to associate the 12 odors with the first set of pictures; in the second session the experimental group was asked to associate the 12 odors with the second set of pictures, while the control group was asked to associate the 12 odors again with the first set of pictures. Two weeks later no differences were observed between experimental and control group in remembering the first set of pictures. On the contrary, the second set of pictures was remembered significantly worse by the experimental group. Thus, the first association to an odor seems to be relatively impervious to forgetting and difficult to modify through subsequent associations.

Finally, Crowder and Schab (1995) found neither facilitation nor interference as a function of odor imagery on odor recognition (see also, Herz and Engen, 1996).

Experiment 2

Is memory for odors affected by same-modality and/or intermodality interference tasks? The second experiment aims at verifying the effects of interference on odor recognition.

Method

Participants

Thirty-six university students ranging in age from 20 to 24 years (M = 22.3 years), divided into three groups, took part in the experiment. They were randomly assigned to one of three experimental conditions. Both sexes were equally represented. Subjects had no impairment to the olfactory, acoustic or visual systems.

Material

A total of 270 olfactory, visual, and acoustic stimuli were used (90 per condition). Odors were almost all pleasant and natural (e. g., chocolate, cinnamon, leather, oregano, pine, rose, rubber, and so on). They were contained in small glasses covered with white paper to prevent participants from having visual cues for identification; substances were replaced every 48 hours, so their concentrations were controlled. The visual stimuli were black and white photographs (9 × 13 cm) representing human faces of males and females seen in front. Their age ranged from about 18 years to 60 years. Finally, the acoustic stimuli were tape-recorded environmental sounds (e. g., a telephone or a bell ringing, a child crying, a train hissing, a cat mewing, a hammer knocking, and so on). All stimuli selected were ecological and natural. They were quite distinguishable, according to the judgment of three independent observers.

Procedure

The experiment consisted of four sessions. In the first (the no-interference condition), participants were asked to sit on a comfortable chair and to either sniff, listen (by earphones), or look at 15 stimuli; they were then requested to recognize the former stimuli from a set of 45 (selecting each target stimulus among three). In the other sessions, held one week apart to avoid learning effects, they were shown a new set of 15 stimuli followed by an interference task. During this task subjects either had to listen, sniff, or look at other olfactory, visual, or acoustic stimuli (18 on average) for 2½ minutes. They were also asked to judge each of them on a 5-point pleasantness scale. Finally, subjects were required to recognize the original set of 15 stimuli from 45. The interference tasks were intermodality (two) and intramodality (one).

For a better understanding of the experimental demands, let us consider a participant in the olfactory condition:

- *First session (no-interference):* The subject sat on a chair and was asked to smell 15 odors, one after the other; each stimulus was exposed for about three seconds, with an interstimulus interval of about 6 seconds. Every five presentations the subject was given 15 seconds to rest to avoid any carry-over adaptation effects. At the end of the acquisition phase the subject was asked to recognize the target odors. The recognition set consisted of the old odor and two new odors (e. g., *cinnamon*–tobacco–soap). For each of the three alternatives, the experimenter asked the question "Is this the odor that you sniffed previously?" Participants were given a short rest every three subsequent presentations. The position of the target stimulus in the triplet was random.
- *Second session:* The subject was exposed to a new set of 15 odors and was shown, at the end of the presentation, some photographs representing human faces for 2½ minutes (if the interference task was visual). For each photograph shown the subject had to say how much he/she liked it, on a scale from 1 (not pleasant at all) to 5 (very pleasant). At the end of such an intermodality interference task, the subject was engaged in the olfactory recognition (about which he had previously been informed).
- *Third session:* At the end of the acquisition of the 15 olfactory stimuli, the subject was given a pair of earphones (if the interference task was acoustic) and was asked to judge the pleasantness of some environmental sounds for 2½ minutes (intermodality interference). Immediately after this, the subject performed the olfactory recognition task.
- *Fourth session:* After the presentation of the 15 olfactory stimuli, the subject was administered the olfactory, intramodality, interference task.

In short, there were two intermodalities interference sessions, one intramodality interference session, and one without interference.

All the sessions (except the first) were counterbalanced among subjects.

The experiment took place in a large and well-ventilated room. Responses were scored for accuracy. For each session the 30 distractors were randomly selected from the set of 90 stimuli, with the restriction to not use the same stimuli for subsequent sessions.

Results

Table 2 shows the mean number of correct recognition (out of 15) and standard deviations for each group. Correct responses underwent three one-way analyses of variance (ANOVA), with olfactory, visual, and acoustic conditions as factors, and no-interference vs olfactory interference vs visual interference vs acoustic interference as levels.

Only the acoustic and visual conditions reached a significant level:

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Table 2
Mean scores and Standard deviations (in brackets) for Acoustic, Visual and Olfactory modalities, as a function of interference.

		Interference		
	Control	Acoustic	Visual	Olfactory
Modalities				
Acoustic	13.3	10	11.8	12
	(.94)	(1.87)	(.90)	(1.38)
Visual	14.3	13	11.4	12.7
	(.47)	(1.29)	(1.44)	(1.35)
Olfactory	10.4	11.3	10.3	10.7
	(1.55)	(1.43)	(1.54)	(1.3)

- acoustic condition: $F(3, 33) = 30.3$, $p < 001$;
- visual condition: $F(3, 33) = 26.3$, $p < .001$;
- olfactory condition: $F = 2.46$

A post-hoc analysis (Tukey test) was carried out to examine the effect of intramodality and intermodalities interference on visual and acoustic conditions (for α .01).

In each analysis the within-modality condition shows the most interference; the between-modalities condition show significantly less interference than the within-modality condition, but more interference than the control condition.

Discussion

The general results of the second experiment indicate that recognition performances for visual and acoustic stimuli are affected by interference tasks (see, e. g., Baddeley, 1986; Brooks, 1967). In fact, in the no-interference condition recognition scores for acoustic and visual stimuli were significantly better than those in the intermodality interference condition, while the intramodality interference condition produced significantly worse recognition scores.

However, unlike visual and acoustic memory, olfactory memory does not seem to be sensitive to interference effects: Neither same-modality nor different-modalities interference scores differed significantly from those of the control group.

Engen et al. (1973) also observed that interference tasks (like counting backwards) also failed to show any effect on recognition of odors. However, such a result could be attributed either to the weak connection between olfaction and language or to the fact that the task demand was too easy, rather than to interference *per se.* Here, it was observed that despite adopting the strongest interference task (as intramodality), no disruptive effects on odor recognition appeared. Olfactory memory thus does not seem to be affected by the use of strategies (as observed in Experiment 1) or by interferences. Plausible reasons for this—as well as the possibility to think of olfactory memory as a distinctive memory system—are discussed below.

General Discussion

In this paper two experiments were carried out to investigate both the effects of strategies and interference tasks on the recognition of odors. Although strategies and interferences represent effective methods to improve or disrupt verbal and visual memory (as observed also in Experiment 2), they failed to show any effect on odor recognition.

The question is: Why do odors behave differently from visual and verbal stimuli? My answer is a theoretical proposal that integrates the issues of the present experiments and some other peculiarities of olfactory memory in a single interpretation.

The main hypothesis lies in the assumption that odors (1) do not give rise to a conscious representation of them and (2) could be stored in memory at a level below consciousness. The sequence from encoding to storage of olfactory information could then occurs through the following steps:

1) subject *(S)* is presented an odor;
2) during encoding *S* is conscious that he/she is smelling an odor (e. g., coffee); but
3) when the stimulus is taken away, *S* lacks a conscious representation of it;
4) the odor is, however, automatically stored in memory; but
5) at an implicit (unconscious) level of knowledge.

The assumption that odors do not give rise to a conscious representation thereof relies mainly on introspective reports: All of us have experienced that recalling an odor is an impossible or particularly hard task. Such a difficulty, however, could depend on the fact that people have no conscious representation of the stimuli experienced (then, we could maintain that a conscious recall implies a conscious representation). Recognition, however, is possible, and it is the only route for odor retrieval, since it is a match between a stimulus already stored in memory with a newly encountered one. Obviously, people can remember that an odor was encountered on one occasion and can also name it; but this does not mean that a conscious representation or the recall of odors is possible. Of course, I am aware that speculations based on introspective reports are not the best scientific demonstrations. But what is the connection between the results of both experiments presented here and the analyses given above? This link is indirect, because we have no methods to observe directly whether a conscious representation of olfactory stimuli actually exists. Hence, I would like to start by examining the effects of strategies and interfering tasks on memory for verbal and visual stimuli. It is well known that while the former improve their retrieval, the latter have a disruptive effect on them (see any book on memory, e. g., Baddeley, 1990, 1998).

I assume that an improvement or disruption of verbal and visual material is possible only because subjects have access to their internal representation of such stimuli. This means that, to be effective, interferences and strategies have to act on these conscious representations. In short, if together with—or soon after—the presentation of the word "dog" people are not able to create an image or to rehearse such a stimulus, then neither strategies nor interferences can affect recognition—and the stimulus is recognized on the basis of its own characteristics. This is exactly what happened in the first experiment: No differences were found among conditions (proportion of hits were about the same for the three experimental groups) and the level of recognition accuracy was independent from the use of any strategy (see discussion of Experiment 1). The main issue here, however, is still that *none* of the strategies used actually affected recognition of olfactory stimuli. In my opinion, this happened because strategies have to act on the *conscious* representations of the stimuli in order to be effective, and this in turn is not possible for the olfactory domain (probably, as suggested from one of the reviewers (and I agree), olfactory representations are mainly perceptual, whereas visual and verbal representations are also conceptual, the latter giving rise to conscious representations, while the former do not). The same is true when adopting interfering tasks: Subjects of an experimental group do not recognize odors worse than a control group because they lack a conscious representation of those odors. Indeed, to create a conscious representation of an odor (e. g., coffee) is a very difficult task, compared to how easy it is to imagine a cup of coffee or to rehearse the word "coffee." Storage and access to olfactory stimuli in memory, then, should not imply an effort but be automatic.

In the introduction some peculiarities (or anomalies) of olfactory memory were discussed. I think the proposal presented above could integrate them in a single interpretation. Such peculiarities (nearly all observed in literature) were as follows:

1) Odor memory is slightly or at all affected by retention intervals.
2) Odor memory is resistant to retroactive interference.
3) Generation of a meaningful label has no effect on subsequent recognition.
4) Verbal rehearsal and counting backwards do not affect recognition of odors.
5) Incidental or intentional learning of odors gives rise to a similar pattern of results.
6) As seen here, neither strategies nor interferences affect recognition of odors.

The assumption that people lack a conscious representation for odors could successfully explain any of these effects, and it also satisfies the scientific criterion of parsimony. People can be conscious of olfactory stimuli only at the encoding and recognition stages, that is, when they are concretely present. Between these periods conscious access to the olfactory trace is not possible. Therefore, subsequent learning experiences cannot affect previously learned odors for which we have no conscious representation. Time passing has no effect on odor memory, for the same reason. Incidental or intentional tasks do not affect the recognition of stimuli that cannot be rehearsed or elaborated, and so forth for all the other anomalies quoted above.

What kind of relationship is there between this proposal and other interpretations on the nature of odor memory?

Engen (1982) suggests that odors are represented in memory as unitary and distinctive events with little attribute redundancy. Odors, then, are learned holistically (in an all-or-none fashion), which explains their relatively low initial acquisition level and their resistance in time (the interference caused from other olfactory stimuli is minimal). Schab (1991), however, suggests that odors acquired in an experimental set are processed differently from those encountered in other contexts. This should explain the little or absent degree of interference between the two conditions (experimental and nonexperimental) and the endurance of olfactory traces. The sturdiness of odor memory could be related to different ways of processing odors rather than to the separate nature of olfactory stimuli. As the author states, this hypothesis, however, needs to be tested experimentally.

Fundamentally, I agree with Engen's point of view that odors could be stored as distinctive and unitary events, and I think that this interpretation does not con-

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trast with, but could be integrate within, the model here presented. The idea that there is no conscious representation for odors can account for their distinctiveness. In my opinion, however, the latter is not sufficient to explain all peculiarities of odor memory and has to be better operationally defined.

The claim that memory for odors is different from visual and verbal memory was examined by Herz and Engen (1996). They applied the criteria of multiple memory systems (MMS) theories (see Roediger, Rajaram, & Srivinas, 1990; Sherry & Schacter, 1987; Schacter & Tulving, 1994), according to which different memory systems are governed by different and distinct mechanisms. The authors maintain that despite the fact that not all the criteria of the MMS theories (i. e., functional dissociation, stochastic independence, and independent neural systems) were satisfied, it remains difficult to consider memory for odors as memory in other modalities.

Furthermore, within the discussion of whether odor memory can be conceptually (or semantically) driven or perceptually driven (see, e. g., Herz & Engen, 1996; Lyman & McDaniel, 1990; Schab, 1991) the above analyses—and the results of the present experiments—seem to suggest that odor memory is perceptual in nature. Indeed, experimental manipulations do not affect recognition of odors.

A last point concerns the possible relationship between the theoretical proposal discussed in this paper and other cognitive theories, as well as the relationship between this theory and other theories on consciousness (see Umiltà, 2000, for a recent review on consciousness). These issues would have to be discussed in more detail in a separate paper; however, a few considerations can be made. The idea that there is no conscious representation of odors can be connected somewhat to theories on implicit and explicit memory (see Graf & Schacter, 1985; Kihlstrom, Schacter, Cork, Hurt, & Behr, 1990; Schacter, 1987; Tulving & Schacter, 1990). Indeed, in implicit tasks, such as fragment or stem completion, amnesic patients show quite normal memory, despite the fact they fail to recall that they were shown certain stimuli. Their access to memory traces is automatic (the same is true for odors). However, whether the acquisition of items (e. g., verbal and visual) in amnesic patients is automatic or effortful, and whether these two conditions can give rise to different issues (as was *not* observed for odors) remains to be demonstrated. Experiments on implicit memory in amnesic patients suggest simply that a stimulus for which there is no recall can be stored, and that access to it is possible only implicitly.

An interesting point of view on the role of consciousness in cognition was advanced by Velmans (1991). The author assumes that no human information processing is conscious, in the sense that consciousness neither takes part nor causally influences cognitive processes. Although the present paper claims that consciousness has no role only in processing of odors, Velman's contribution can be useful. The author in fact outlines some situations in which information may indeed enter memory and be recalled without consciousness. Such conditions are hypnosis, blindsight, and "masked priming" studies. I think that the hypothesized uniqueness of odor memory compared to other modalities can be effectively tested under these circumstances (see, for instance, Olsson, Jonsson, & Faxbrink, in press, for a review on implicit memory for odors).

Finally, the proposal presented here is difficult to integrate with any of the theories on consciousness (see Umiltà, 2000). Indeed, being either of the interactionist or unitary type they do not give attention to the possibility of having unconscious representations of newly experienced stimuli. However, a discussion on these issues is beyond from the main purposes of this contribution.

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