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Interference and facilitation in short-term memory for odors

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This study investigated short-term memory for odors using a four-alternative, forced-choiced recognition paradigm. Stimuli were the odors of 36 common food substances. Twelve subjects were tested in each of four conditions, which differed in the activity performed during the retention interval. Recognition performance was poorest when subjects free associated to an additional odorant presented during the retention interval. Thus, interference from interpolated events does occur in odor memory. Recognition performance was best when the subjects free associated to the name of the target odorant during the retention interval. Thus, the memory code for odors may incorporate semantic information. Remembering odors appears, therefore, to be governed by the same principles as remembering stimuli in other modalities.

Processing odor information has been thought to differ in important ways from processing information in other modalities. Recalling the name of a presented odor, for example, is surprisingly difficult (e.g., Cain, 1979; Desor & Beauchamp, 1974). Associations are acquired more slowly when odors are used as the stimuli in a paired-associate task than when visual or verbal items are used (Davis, 1975, 1977). Furthermore, when odors are the to-be-remembered items, forgetting occurs more slowly than is typical with other material (Engen, Kuisma, & Eimas, 1973; Engen & Ross, 1973; Lawless & Cain, 1975). In this study, we will investigate further the nature of forgetting in odor memory by examining the effects of different activities performed during the retention interval.

Early researchers (Engen & Ross, 1973; Lawless & Cain, 1975) emphasized that forgetting of odors was slow relative to that for pictures or words. Furthermore, initial recognition of odors was poor. The hit rate for odor stimuli on an immediate two-alternative, forced-choice test was only 70%; after 1 year, the rate dropped a mere 10% (Engen & Ross, 1973). For highly distinctive odorants, Lawless and Cain (1975) reported initial recognition at 85%; after 28 days, performance was only slightly poorer, at 75%. In experiments with pictures and words as stimuli, however, performance on comparable recognition tests was high initially and decreased rapidly (Nickerson, 1968; Shepard, 1967).

Why are odors so poorly remembered initially and so well retained over time? Engen and Ross (1973) suggested that the differences between memory for odors and pictures were due to differential coding (see also Engen, 1977). They speculated that a picture contains many attributes which can serve as a basis for encoding, thereby producing a rich trace. The rich trace can be recognized easily on an immediate test but is subject to interference from later stimuli which share some of its attributes. An odor, they suggested, produces a "unitary perceptual event"; it has fewer perceptual features to encode. The less rich trace leads to more errors in immediate recognition, but the absence of attributes held in common with other stimuli makes the trace resistant to interference.

Engen (1977) cited the relatively flat forgetting functions obtained in long-term memory studies as evidence that odor memory is impervious to interference. Engen et al. (1973) provided direct evidence that odor memory is resistant to interference in a short-term situation. In their study, subjects inspected either one or five odorants, counted backwards during a 3- to 30-sec retention interval, and then were tested with a yes/no recognition probe. Recognition did not decrease with the length of the retention interval, that is, with the amount of interpolated activity. Furthermore, performance was not reliably poorer than for five control subjects who did not count backwards during the retention interval. Engen et al. concluded that the odor memory code was "relatively isolated from the interference of other sensory events" (p. 224).

Can the odor memory code include nonperceptual information? Engen and Ross (1973) provided subjects with correct verbal labels during odor presentation and found no advantage on a subsequent recognition test over a no-label group. Lawless and Cain (1975) required subjects to label odor stimuli with personally meaningful descrip-

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tors during inspection; labeling did not promote better recognition. Both experiments suggested that semantic information could not be incorporated in the odor memory code.

The conclusions about the characteristics of odor memory are generalizations based on limited data. With so little evidence, a given result may reflect either a basic principle or some idiosyncratic aspect of the experimental logic or procedure. The claim that slow forgetting is a unique characteristic of odor memory, for example, has since been retracted by Lawless (1978). He demonstrated that it was based on an invalid assumption, namely that pictures are representative of all visual stimuli, so that different forgetting rates for pictures and odors imply a difference between the visual and olfactory memory systems. Lawless (1978) compared the forgetting functions for odors, pictures, and simple visual forms; the curves for odors and forms were parallel, but the curve for pictures was different. Stimulus modality does not, therefore, determine rate of forgetting.

Are Engen et al.'s (1973) results satisfactory evidence that odor memory is generally impervious to interference? Most authorities accept that, in short-term memory studies, interference occurs because rehearsal of the memory items is disrupted. Interference is selective: The degree of interference from a given distractor depends on the nature of the memory items being rehearsed. Increasing similarity between the to-be-remembered and distractor items increases interference (Corman & Wickens, 1968; Wickelgren, 1965). Interference also increases if the to-be-remembered and distractor items are processed in the same, rather than different, modalities. For example, Salthouse (1975) showed subjects a 25-item array with seven circled targets. When the subjects had to remember the identity of the targets, interpolated backwards counting produced more interference than a mental rotation distractor task, but when subjects had to remember the locations of the targets, the mental rotation task produced more interference. (For further examples, see Bower, 1972; Deutsch, 1970; Salthouse, 1974.) The Salthouse (1975) study demonstrates explicitly that interference from backwards counting varies with the nature of the memory items. The absence of interference in the Engen et al. study may indicate that odor maintenance and counting can be performed simultaneously at little cost, not that odor memory is impervious to interference.

Engen et al. (1973) point out that it is difficult to conceive of olfactory rehearsal, that one may be unable to "smell" a stimulus mentally in the same way as one can "see" a mental image. They reject as unreasonable the possibility that odor memory can be maintained in one channel while a verbal task is performed in another. Nevertheless, the stimulus which most likely will be processed in the same way as odor memory items is an additional odor. Odor memory is already known to be sensitive to similarity manipulations; recognition accuracy decreases as similarity between targets and lures increases (Engen & Ross, 1973; Jones, Roberts, & Holman, 1978). To test for interference in odor memory, our experiment included a condition in which a further olfactory stimulus was processed during the retention interval. We predicted that subjects who processed a further odor would recognize fewer targets than subjects who had no restraints on retention interval activity.

The claim that the memory code for odors contains only perceptual information is also debatable. We know that nonverbal auditory and visual stimuli are better retained if they are encoded in terms of semantic, not just perceptual, features (Bartlett, 1977; Brown & Lenneberg, 1954; Daniel & Ellis, 1972; Freedman & Haber, 1974). Evidence exists that odor memory also is influenced by nonperceptual characteristics of the stimuli. For example, Davis (1975) found that when odors were the stimuli in a paired-associate task, odors rated as highly familiar were linked more rapidly to responses than were unfamiliar odors. Lawless and Cain (1975) found a moderate correlation between codability and recognition accuracy after a long retention interval (28 days). Eich (1978) reported that when an unstudied odor elicited recall of a studied word, it apparently did so because it activated semantic information. Davis (1981) found that subjects given an odor identification task before and after a relevant or irrelevant color cue showed improved performance after relevant, but not irrelevant, cues, particularly when the odors were familiar. Rabin and Cain (1984) showed that long-term retention of odors was positively correlated with rated familiarity. These studies indicate that nonperceptual characteristics of an odor can affect memorial performance; it may be possible to include semantic information in the odor memory code. To test for effects of semantic information in short-term memory for odors, our experiment included a condition in which the name of a to-be-remembered odor was presented during the retention interval. We predicted that subjects who processed the name of the target would perform better than subjects who processed the name of an irrelevant item.

METHOD

Subjects

The subjects were 22 male and 26 female students and faculty members at Queen's University. By self-report, each subject had a normal sense of smell, did not smoke, and was not asthmatic. The subjects were assigned randomly to four groups with 12 subjects per group.

Stimuli

The stimuli, listed in Table 1, were the odors of 36 common food substances. Food substances were used rather than chemical entities so that subjects would be familiar with at least their names. The odorants were arbitrarily grouped into the following six categories: condiments, fruit, herbs and spices, spices, sweets, and vegetables.

The odorants in the fruit and sweets categories were prepared as solutions. The concentrations used for each of these odorants, calculated as volume solute/volume solute plus volume solvent, are shown in Table 1. A pilot study determined the concentrations used: Eight subjects judged which of three different concentrations of each odorant matched in perceived intensity a .03 concentration of a ben-

Table 1
Odorants Used as Stimulus Items

Category	Odorant	Source	Concentration
Condiments	barbecue sauce	Heinz	undiluted
	ketchup	Heinz	undiluted
	seafood sauce	Elco	undiluted
	soya	China Lily	.60*
	tabasco	McIlhenny Co.	.50*
	worcestershire	French's	.60*
Fruit	banana	propylene glycol	.15*
	lemon	citral	.03†
	orange	extract	.15*
	pineapple	extract	.10†
	raspberry	B-ionine	.03†
	strawberry	strawberry aldehyde	.03†
Herbs & Spices	basil		
	cloves		
	nutmeg		
	oregano		
	rosemary		
	thyme		
Spices	chili powder		
	curry powder		
	ginger		
	onion powder		
	black pepper		
	paprika		
Sweets	butterum	Wagner's extract	.10*
	vanilla	Wagner's extract	.25*
	butterscotch	Wagner's extract	.10*
	chocolate	Wagner's extract	.10*
	maple	Wagner's extract	.10*
	mocha	Wagner's extract	.10*
Vegetables	beet		
	carrot		
	green pepper		
	olive		
	red pepper		
	tomato		

**Diluted in distilled water.* *†Diluted in diethyl pthalate.*

zaldehyde and diethyl pthalate solution. Herbs and spices were presented in dried form, as commonly obtained in grocery stores. Vegetable juice was extracted directly from fresh vegetables. No attempt was made to control the intensity of the odors of the herbs, spices, and vegetables.

All odorants were presented in 1-g glass vials with screw-cap lids. Masking tape covered the outside walls of the vials, and food coloring was added to all liquid odorants to minimize the visual information available to subjects. Each vial contained 2 ml of odorant. All odorants were prepared within 24 h of first use and discarded within 48 h of first use. Between uses, the vials were cleaned with detergent, distilled water, and pure acetone, and baked at 270°C.

Procedure

The subjects were tested individually in a well-ventilated room. Each subject received six trials with short rests between trials. Each trial involved odorants from only one category, and each category was used on exactly one trial per subject. Two arbitrary orders of category presentation were used. Half the subjects received the order: fruit, condiments, spices, sweets, vegetables, herbs and spices; the other half received the reverse order.

Whenever an odorant was presented, the subject was handed an open vial and instructed to hold the vial by its base. He/she was allowed 2 sec to sniff the odorant without letting the mouth of the vial touch any part of his/her body. Throughout the experiment, an interstimulus interval of 12 to 15 sec was used to ensure that adaptation effects would dissipate between odorant presentations (see Cain & Engen, 1969; Pryor, Steinmetz, & Stone, 1970).

A trial consisted of three stages: an acquisition stage, a 26-sec retention interval, and a recognition test. In the acquisition stage, two odorants were presented, one at a time, to the subject. The four conditions had different retention interval tasks. In the control condition, the subjects were free to do whatever they wished. The other three conditions included a distractor task: The subject was required to verbalize associations to a presented word or odorant. In the same-modality distractor condition, the distractor was a third odorant from the same category as the to-be-remembered odorants. In the semantically unrelated distractor condition, the distractor item was the name of the distractor in the same-modality distractor condition. In the semantically related distractor condition, the distractor was the name of one of the to-be-remembered odorants.

The distractor item was presented for 2 sec in the middle of the 26-sec retention interval, that is, 12 sec after the second to-be-remembered odorant. The free association task occupied the remaining 12 sec of the retention period. In both semantic conditions, the subjects were told that the words given as distractor items might or might not be related to one of the odors presented during the acquisition stage.

On the recognition test, the subjects sniffed four test odorants and then indicated the odorant that they thought had been presented in the acquisition stage. On each trial, the target was chosen at random from the two to-be-remembered odorants. In the semantically related condition, the target was always the stimulus whose name was given as the distractor item. The position of the target odorant in the sequence of four test odorants was determined randomly on each trial.

On each trial, up to six odorants, always drawn from the same category, were presented in the following positions: two for inspection, one as the distractor (same-modality distractor condition only), and three as lures in the recognition test. Across subjects, each odorant was presented equally often in each position for each condition.

RESULTS AND DISCUSSION

Table 2 shows the mean hit rate in each of the four conditions. Performance differed significantly with condition [$F(3,40) = 22.46$, $p < .001$], but there was no effect of category order or its interaction with condition (both Fs < 1). The reliability of the theoretically interesting differences was assessed with orthogonal comparisons. The hit rates in the same-modality distractor and empty control conditions differed reliably [$F(1,40) = 9.60$, $p < .01$]. The hit rates in the semantically related and unrelated distractor conditions also differed [$F(1,40) = 35.51$, $p < .001$].

Table 2
Recognition Memory Performance in the Four Conditions

	Condition			
	Control	Same-Modality Distractor	Unrelated Semantic Distractor	Related Semantic Distractor
Mean Hit Rate	.556	.375	.486	.833
Standard Deviation	.192	.104	.132	.101

In addition, Tukey tests were used to assess all possible pairwise comparisons. The hit rate in the semantically related condition was significantly different from the hit rates in each of the other three conditions ($\alpha = .01$). The hit rate in the same-modality distractor condition was significantly different from that in the control condition ($\alpha = .05$), but the semantically unrelated distractor condition did not differ from either the control or the same-modality distractor conditions.

Interference by a Same-Modality Distractor

As evident from Table 2, the hit rate in the same-modality distractor was 18.1% lower than in the empty control condition.[1] Clearly, a distractor task can interfere with memory for an odor.

Engen et al. (1973) failed to find interference, but their experiment differed in several respects from the current one. Some of the procedural differences clearly cannot explain the discrepancy in results. For example, their subjects each received 100 trials; a trial involved one or five studied odorants and a single yes/no probe. Our subjects each received 6 trials; a trial involved two studied odorants and a four-alternative, forced-choice recognition test. These methodological differences can account for differences in the overall level of performance, but do not readily explain the difference in the amount of interference obtained.

A further change concerns the test for interference: Engen et al. tested for interference by varying retention interval duration, whereas we varied the retention interval task. Engen et al. found that accuracy after 30 sec was as high as after 3 sec and concluded that interference was negligible. There is a problem, however, with this interpretation of the data. They also obtained a significant increase in accuracy as retention interval lengthened from 3 to 12 sec. They acknowledged that an additional factor, such as sensory adaptation, must have depressed performance at the 3- and 6-sec retention intervals. Although there is nothing intrinsically wrong with testing for interference by manipulating length of retention interval, the presence of a contaminating factor in this particular experiment renders the comparison of performance after 3 and 30 sec uninterpretable. The retention interval data do not permit, therefore, a conclusion about interference. However, they also included a task manipulation. Because performance after the 30-sec retention interval lay above 70% and did not improve when the retention interval was empty, interference seems to have been truly negligible in the Engen et al. study, not just masked by an additional effect.

The remaining methodological difference is the distractor task used. Counting backwards did not disrupt the maintenance of the odor memory code appreciably, but free associating to a further odorant did. Interference in odor memory is, apparently, selective.

Because the same-modality distractor involved both smelling an additional odor and verbalizing free associates, the source of the interference could be olfactory and/or semantic. The semantically unrelated distractor, in contrast, provides only semantic interference. Because performance in the semantically unrelated distractor condition was only 7.0% poorer than in the empty control condition, a nonsignificant difference, most of the 18.1% decrease associated with the same-modality distractor condition appears to reflect olfactory interference. The possibility of some semantic interference cannot be completely discounted, however, because the unrelated semantic distractor condition was not significantly different from the same-modality distractor condition. It is clear from Table 2, however, that performance in the unrelated semantic distractor condition was closer to that in the control condition than in the same-modality distractor condition.

It is relevant that our subjects had difficulty identifying the odors. The free associates elicited by the distractor odorant included the odorant's name on only 4 of the 72 trials. Because the to-be-remembered odors were unlikely to evoke semantic information, they had to be encoded primarily as perceptual entities, and were, consequently, more susceptible to olfactory than to semantic interference. With more easily identifiable stimuli, however, a semantic component might be included in the memorial codes, and more interference from a verbal distractor might occur.

Two conclusions emerge. First, odors are encoded largely as perceptual entities, just as previously claimed (Engen & Ross, 1973; Lawless & Cain, 1975). Second, odor memory suffers from interference by same-modality interpolated events, just like memory in other modalities (see Bower, 1972; Deutsch, 1970; Salthouse, 1974, 1975). Odor memory is a separate, but not a qualitatively different, memory system.

In long-term studies, retention of odors is good (Engen & Ross, 1973; Lawless & Cain, 1975). Why did the many odors encountered in everyday life not interfere substantially with the memory items in these experiments? Because rehearsal disruption is unlikely to be the mechanism of interference in long-term studies, interference here may be different from interference in short-term situations. Nevertheless, the degree of interference produced by interpolated events still depends on their similarity to the target items (see, e.g., McGeoch & McDonald, 1931). Slow forgetting, therefore, would be explained if the target odors were very dissimilar to the interpolated odors. Both of the cited odor experiments included common household products as stimuli, so that the stimuli were probably perceptually quite similar to other household odors. However, the memorized odors may have been dissimilar to everyday odors in a different way.

A memory trace is the result of the mental operations performed during encoding. When trying to memorize an odor, the subject must attend to perceptual features and may attempt to describe or label those features. Such processing is probably rare in everyday life; although exposed to many odors, we attend to meaningful events, such as dinner cooking, rather than to the particular characteristics of the associated odors. Odors that are relatively unnoticed and unprocessed should not interfere appreciably with memory for well-encoded odors. In contrast, our experiment required subjects in the same-modality distractor condition to attend to the interpolated odor. Moreover, free association may be very similar to the processing that subjects performed during encoding. In fact, some control-condition subjects reported using verbal mediation to help them remember the target odorants; the verbal mediation ranged from vague qualitative descriptors to specific, although not necessarily correct, labels. In this experiment, we suggest that interference was particularly salient because the target and distractor items were encoded in similar ways.

Is odor memory peculiarly free from interference? The present experiment shows clearly that interference can occur. Our position is that odor memory's apparent resistance to interference results from the relative rarity of potentially interfering events. The general rule that forgetting is caused by interference from similar events is as true for olfactory memory as for other memory systems.

Facilitation from Semantic Information

The hit rate in the semantically related distractor condition was 34.7% higher than in the semantically unrelated distractor condition and 27.7% higher than in the empty control condition. Clearly, semantic facilitation can occur in odor memory.

As with interference, our data show an effect that earlier researchers (Engen & Ross, 1973; Lawless & Cain, 1975) failed to find. Engen and Ross (1973) reported no advantage on a recognition task for subjects given verbal labels at encoding time over those given no labels. Their "no-verbal-label" subjects were to identify the odorants, and, at the end of the acquisition stage, were given the correct answers and a further opportunity to smell the odorants, as feedback. It is not correct, therefore, to say that these subjects received no verbal code. The comparison to subjects who did receive verbal labels is meaningless.

Cain (Rabin & Cain, 1984) has himself suggested that the experiment reported by Lawless and Cain (1975) was not sufficiently sensitive to find an effect of codability on odor memory. The labels generated by the first group of subjects may not have been more useful mnemonically than the pleasantness ratings required of the other subjects. Furthermore, the null effect of codability was obtained by correlating average codability with average recognizability; a more sensitive test would look at the probability of individual subjects' remembering each odor as a function of how accurately they could identify it.

One might argue that the superior performance in the semantically related distractor condition reflects experimental artifact. In the semantically related distractor condition, the recognition target was always the odor named during the retention interval. Subjects might become aware of this fact. If so, they could simplify the memory task by forgetting the other studied odor. Because recognition accuracy increases as the number of target odors decreases (Engen et al., 1973), the superior performance in the semantically related distractor condition may reflect only the functionally smaller memory set. A second artifactual interpretation is that subjects in the semantically related distractor condition were not remembering any odors; having learned that the named odorant was the test target, they simply selected whichever test odor matched the name given.

Two aspects of the data argue against the artifactual explanations. Both explanations assume that subjects learn of the relation between the distractor item and the recognition target and adopt an advantageous strategy. On the first trial, however, subjects could not have known that the named odor was always the recognition test target. Table 3 shows the number of correct recognitions in the semantically related and unrelated distractor conditions separately for each trial. The means indicate that first-trial performance was better in the semantically related than in the semantically unrelated distractor condition. Secondly, if subjects were learning to use a strategy, performance in the semantically related distractor condition would have improved over trials. Superiority on the semantically related distractor condition is consistent across trials. The advantage in the semantically related distractor condition, therefore, most likely indicates semantic facilitation.

Exactly how does semantic information improve recognition performance? In other modalities, experimental findings indicate that semantic facilitation results from enriched encoding, not more retrieval information (e.g., Bransford & Johnson, 1972; Daniel & Ellis, 1972; Dooling & Mullet, 1973). Accordingly, we propose that, just as a conflicting stimulus can disrupt rehearsal, so a complementary stimulus can enhance it. During encoding, subjects probably generated and used correct odor names rarely. When names were provided during the retention interval, the subjects could incorporate that additional information into their encodings of the otherwise largely perceptual events. In a long-term-memory study, accurate labels were associated with better recognition performance than were vague labels (Rabin & Cain, 1984). Similarly, on our recognition test, subjects were more able to match a rich, semantic trace than a less semantic trace to the correct probe.

Semantic facilitation in short-term memory fits well with growing evidence that the mental code for odors can incorporate semantic information (Davis, 1975, 1981; Eich, 1978; Rabin & Cain, 1984). Either the memory code for odors can include both perceptual and semantic

Table 3
Number of Subjects (Out of 12) Responding Correctly on Individual Trials in the Semantic Distractor Conditions

	Trial					
Distractor Type	1	2	3	4	5	6
Semantically Unrelated	6	5	4	7	8	5
Semantically Related	11	10	9	10	10	10

features or odors can be encoded by both olfactory and verbal codes (dual-coding), as proposed by Paivio for visual stimuli (e.g., Paivio, 1971). The code's semantic component varies with encoding conditions: It may be minimal in the absence of nonperceptual information, but be quite salient for a familiar, named stimulus. Thus, although the odor memory code seems to be normally perceptual in nature, under some circumstances it may include semantic information.

CONCLUSIONS

A decade ago, what little was known about odor memory suggested that odor memory was a unique system. Lawless and Cain (1975) stated that odor memory was relatively unaffected by variables known to be important to memory in other modalities. Today, it seems that encoding and test variables have comparable effects when the stimuli are sights, sounds, and odors.

Retention improves if an item is encoded in terms of semantic characteristics rather than only perceptual characteristics. The effect holds for words (Craik & Lockhart, 1972), faces (Bower & Karlin, 1974; Warrington & Ackroyd, 1975), colors (Brown & Lenneberg, 1954), complex forms (Clark, 1965; Daniel & Ellis, 1972), environmental sounds (Bartlett, 1977), pictures (Bower, Karlin, & Dueck, 1975; Freedman & Haber, 1974), and now odors (Rabin & Cain, 1984). The present experiment extends this knowledge by showing that short-term odor recognition may also benefit from semantic encoding.

Slow forgetting, once considered unique to odor memory (Engen, 1977; Engen & Ross, 1973; Lawless & Cain, 1975), has also been demonstrated for voices (e.g., Legge, Grosmann, & Pieper, 1984) and simple visual forms (Cermak, 1971; Lawless, 1978). The present study expands our understanding of the forgetting of odors by showing that interference occurs when the target and distractor items are similar. This finding is consistent with the decrease in recognition accuracy caused by increasing target-lure similarity (Engen & Ross, 1973; Jones et al., 1978). It also accords well with studies demonstrating selective interference in memory for tones (Deutsch, 1970), imaged words (Bower, 1972), and verbal or spatial information (Salthouse, 1974, 1975). Memory for odors does appear to operate on the same principles as memory for stimuli in other modalities.

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NOTE

1. Input position and test position data will not be examined for additional evidence of interference. Only one input position and one output position were tested on any one trial; because each trial involved a different odor category, input and test position are confounded with odor identity, so that effects are uninterpretable.

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