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Odor Recognition Memory: Two Encoding Trials are Better Than One

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Abstract

The primary purpose of this study was to determine the effect of one versus two encoding trials in the classical yes/no recognition memory paradigm using olfactory stimuli. A group of 24 young adults rated 18 standard microencapsulated odorant targets for familiarity (first encoding block) or pleasantness (second encoding block). Once-encoded targets were in only one block and twice-encoded targets were in both, with items counterbalanced across participants. Participants performed a 20-min nonverbal distractor task followed by a yes/no recognition test incorporating 18 additional odors as foils. Memory performance for twice-encoded targets was superior to that for once-encoded targets. For once-encoded targets, performance did not differ between those rated for familiarity versus those rated for pleasantness. Less pleasant odors produced overall better recognition, with a tendency for less familiar odors to produce overall better recognition. There was a tendency for the second encoding trial to have a larger effect for less pleasant or familiar odors than for more pleasant or familiar odors. The main conclusion is that recognition memory for odors is better for items encoded two times than for items encoded only once. Implications of these findings and suggestions for future research are discussed.

Key words: familiarity, multiple encoding, odor recognition memory, pleasantness

Introduction

In the classical yes/no recognition memory paradigm, subjects encode a set of target items during a study task, and later are asked to distinguish them from distractors in a mixed presentation. Research over the past century has generally found that repeated encoding improves performance on such tasks for a variety of predominantly verbal non-olfactory stimulus types (Mulhall 1915; Postman and Rosenzweig 1956; Cooper and Pantle 1967; Hintzman 1970; Chabot et al. 1976; Tussing and Greene 1999; Kelley and Wixted 2001; Jones 2005). There are some exceptions to this pattern; for example, Rose and Sutton (1996) found that recognition memory was not enhanced for words presented multiple times in variable encoding conditions as compared with words presented only once. There also have been numerous studies of recognition memory for olfactory stimuli (e.g., Gordon 1925; Engen et al. 1973; Engen and Ross 1973; Lawless and Cain 1975; Herz and Engen 1996; Zucco 2003; Larsson et al. 2009). This research has found both similarities and substantial differences between olfactory and non-olfactory recognition memory. For example, it has been argued that, as compared with visual and auditory stimuli, previously experienced odors are generally recognized less well a short time after study, but are forgotten much more slowly (for reviews, see Schab 1991; Herz and Engen 1996). These and other differences have led to the suggestion that olfactory memory may merit consideration as a separate memory system with modality-specific functional properties (Herz and Engen 1996). Therefore, it cannot be taken for granted that even well-established general principles of memory function will apply in olfaction, including the facilitative effect generally found in the non-olfactory literature for repeated study encoding in the classical yes/no recognition memory paradigm.

Published results on olfactory recognition memory do not lead to a clear prediction regarding the effect of repeated encoding, although there is evidence that increasing target-odor exposure time results in enhanced perceptual discrimination (Li et al. 2006). Two studies by Jehl and colleagues have provided relevant but contradictory evidence regarding the effects of repeated encoding—which they referred to as familiarization—on recognition memory performance. Jehl et al. (1995) found facilitation of recognition from multiple exposures (separated by 24 h) in an unusual procedure that combined a very short-term (20 s) and a long-term (24 h) recognition memory test. Although their procedure was quite unlike the classical paradigm with which we are concerned here, it strongly suggests that long-term recognition memory for odors may benefit from repeated encoding. On the other hand, in a second study that also combined long- and short-term odor recognition, Jehl et al. (1997) compared recognition memory when there had been a previous familiarization phase a week earlier (their "no-label" group, repeated encoding of each odor) to no preliminary exposure (their "no-learn" group, only one encoding of each odor). In the long-term (24 h) condition, a single encoding resulted in significantly better performance than repeated encoding, while in the short-term (20 min) condition, there was an insignificant difference, numerically in the same direction as the long-term condition. These results strongly suggest that prior exposure may have no effect on or actually interfere with subsequent recognition memory performance. They not only disagreed with the results of Jehl et al. (1995), but also were quite different from the results typically obtained with non-olfactory stimuli.

Stevenson (2001) suggested that there may be a set of olfactory-specific memory processes that he called "odor sensory memory." This includes phenomena such as the improvement in ability to discriminate an odor as the result of increased exposure. Odor sensory memory is presumed to interact with episodic and semantic memory and, therefore, to be a factor in odor-specific olfactory memory phenomena. For example, it has been suggested that the poor performance on olfactory recognition for odors immediately after study may be due to relatively poor discrimination of odors and of their memory traces during encoding (Cain and Potts 1996). It is possible that the odor sensory memory processes, which can sharpen discrimination and similarity judgments (Rabin 1988; Jehl et al. 1995), could, in turn, benefit odor recognition performance via processes that are not directly associated with episodic memory functioning.

Odor familiarity and recognition memory

Familiarity is a characteristic of odors that has played a prominent role in studies of olfactory recognition memory. A number of memory studies in which familiarity ratings for the odor stimuli were obtained during the study phase have reported significant correlations for familiarity and hit rate, such that odors rated as more familiar during study were more likely to be correctly recognized at the time of test (Murphy et al. 1991; Larsson and Bäckman 1993, 1997). There have also been studies in which odorants had been classified as familiar or unfamiliar pre-experimentally, allowing the use of high versus low familiarity as a discrete independent variable in the experimental design. Using this method, significantly higher mean discriminability on recognition memory tests has been obtained for familiar as compared with unfamiliar sets of odors (Öberg et al. 2002; Larsson et al. 2006). This is contrary to the effect generally found using non-olfactory materials, where recognition memory is usually better for less familiar stimuli such as low-frequency words (see Yonelinas 2002 for a review and discussion). Larsson et al. (2006) proposed that in their study, a familiarity advantage may have resulted from the lack of "semantic and contextual factors" in their unfamiliar odor samples, whereas the activation of such factors in their familiar odors could have supported later recognition. Their explanation points to a contrast between novel odors and the kinds of unfamiliar stimuli typically used in non-olfactory recognition memory studies: mnemonically relevant semantic and contextual factors can generally be produced with little effort for unfamiliar verbal or pictorial stimuli by comparing them with familiar concepts using shared features. This kind of feature decomposition may be much less available for odors because they are usually perceived holistically (Stevenson and Boakes 2003). The question remains whether relatively less familiar, but previously encountered odors (which might have at least some semantic and contextual connections available) would have the same disadvantage for recognition performance as novel odors do.

Odor pleasantness and recognition memory

Pleasantness is an odor characteristic that has played a surprisingly small role in odor recognition memory studies. There is one study (Larsson et al. 2009) that evaluated study-phase ratings of pleasantness in terms of association with later recognition-test performance for the same participants, reporting a higher hit rate for unpleasant, as compared with neutral and pleasant odors. It should be noted, however, that all of the odor stimuli in the Larsson et al. study were very unfamiliar, which limits the generalizability of the findings. Therefore, the question remains whether more familiar unpleasant odors would produce the same facilitative effect found by Larsson and colleagues for less familiar unpleasant odors.

Verbal labels

Several researchers have employed encoding elaboration strategies during the study phase in order to compare the yes/no recognition-test performance across different encoding conditions. The most commonly employed elaboration has involved verbal labeling of odors, which repeatedly has been shown to improve odor recognition performance as compared with odor-only encoding (Lyman and McDaniel 1990; Larsson and Bäckman 1993; Jehl et al. 1997; Frank et al. 2011). In particular, the overt generation of labels, especially correct labels, for odor stimuli during the study phase has been shown to enhance recognition-test performance (Rabin and Cain 1984; Jehl et al. 1997; Lehrner et al. 1999). Even when subjects are not instructed to produce verbal labels during the study phase, Schab (1991) has pointed out that the issue remains important, because probably all odor recognition memory experiments are "contaminated" by covertly generated verbal labels or descriptions, particularly if subjects are aware during the study phase that they may be expected to remember the odors.

Objectives of the present study

The main objective of the present study was to assess the effect of one versus two study presentations of odors on recognition memory, with our hypothesis being that a second encoding trial would enhance recognition performance. In order to maximize the opportunity for increased depth and breadth of meaningful processing of odor stimuli and therefore for a double-study advantage in recognition performance, our single-study conditions involved ratings of either familiarity or pleasantness, whereas our double-study condition involved both ratings, with a varying number of odor trials intervening between the first and second study trials of the repeated odors. An additional question was whether recognition performance would vary as a function of encoding task, assuming that there could be different depths of processing required in rating for pleasantness as compared with rating for familiarity.

The second objective of this study was to explore the association between recognition memory performance measures and the odor qualities of familiarity and pleasantness. The odor samples we selected possessed a considerable range of familiarity and pleasantness ratings, but all of them were sufficiently familiar to be used in a standard clinical odor identification test. Two different sets of familiarity and pleasantness ratings were available: ratings made by the subjects during the study phase of this study, and a published norm that included those ratings on the same standard stimuli (Doty et al. 1984). Based on the review above, our hypothesis was that there would be better recognition performance for less pleasant odors. For odor familiarity, we could make no specific prediction because there is evidence to support either a recognition advantage for low-familiarity odors (mostly by analogy with the non-olfactory literature) or a recognition advantage for high-familiarity odors (based on several olfactory studies). An additional consideration is that pleasantness and familiarity ratings of odors seem to be strongly and positively correlated; for example, $r = 0.69$, $P < 0.001$ based on the norms of Doty et al. (1984) for the stimuli we used. This suggests that the two odor qualities will have similar relationships with odor recognition memory, and therefore favors the low-familiarity advantage alternative (by analogy with the low-pleasantness advantage described above). Given these considerations, we predicted that the judgments of familiarity and pleasantness produced by our subjects during the study tasks would correspond well to the norms of Doty et al.

The third objective was to assess the association between recognition memory performance and retrospectively reported covert odor labeling (reported at the time of test, but in reference to the study phase). Our primary aim in this study was to focus subjects' attention during the study phase on the odors per se, rather than on possible labels for the odors. Thus, we did not inform subjects that they would be tested on their memory for the odors, nor did we ask subjects to generate labels during the study phase. During the recognition test, however, when subjects stated that a given odor had been presented during study, we asked them whether they remembered thinking of a verbal label at that time, and, if they did, to provide it. We predicted that subjects would be more likely to retrospectively recollect a verbal label when the odor had actually been presented before (a "hit") than when it had not (a "false alarm").

The fourth and final objective was to examine the relationship of the Affective Impact of Odor (AIO; Wrzesniewski et al. 1999) questionnaire with odor recognition performance. The AIO measures the impact of odors in everyday life, particularly, the importance of odors for individuals. It looks specifically at the impact of odors on evaluations of people, places, foods, and cosmetic products. Individuals with higher scores on the AIO are more likely to report odor-evoked memories, to pay more attention to odors in their everyday lives, and to have preferences versus dislikes for odors based on associated preferences and dislikes for particular people, places, and things (Wrzesniewski et al. 1999). We hypothesized that relatively greater AIO scores could be associated with greater depth of processing during study, and therefore would be positively correlated with recognition memory performance.

Materials and methods

Participants

Data were collected from 24 undergraduates (11 males and 13 females) attending the University of California, Davis, whose ages ranged from 18 to 23 (Mean = 19.75, SD = 1.59) and whose years of education averaged 14.2. Participants were recruited via the Psychology Department and received course credit for their participation. The institutional review board of the University of California, Davis approved the study and all participants gave written informed consent.

Given cross-cultural differences in odor perception, recruitment was limited to lifelong residents of the United States. Exclusionary criteria during recruitment included history of smoking, allergies, asthma, or pulmonary disease; moreover, participants could not have current cold or flu symptoms or any other ailment that could affect odor processing. Additionally, at the beginning of the study, potential participants had to perform satisfactorily in two odor-screening tests, the Alcohol Sniff Test (AST; Davidson et al. 1997) and the American version of the Pocket Smell Test (Jackman and Doty 2005). Three trials of the AST were administered, and potential participants had to detect the smell of alcohol at an average distance of ≥5 inches from the nostril in order to continue with the study. The final sample of 24 participants (out of a total of 34 who were screened) yielded an AST mean of 7.31 and standard deviation of 2.24. Qualifying subjects correctly identified three out of three odors on the Pocket Smell Test (in a clinical setting, an error would indicate that further testing be done to quantify smell loss).

Materials

The odor stimuli were 36 of the 40 microencapsulated odors from the University of Pennsylvania Smell Identification Test (SIT; Doty et al. 1984). The four excluded odors (cheddar cheese, fruit punch, lemon, lime) did not differ significantly from the included 36 on mean familiarity, $t(38) = 0.897$, $P = 0.621$ or mean pleasantness, $t(38) = 1.17$, $P = 0.246$, based on rating data norms reconstructed from Figure 2 of Doty et al. (1984). These 36 odors comprised the recognition-test items for all participants; each participant was given half of the odors in both the study and test phases, whereas the other half of the odors was given only during the test phase. Note that the subjects in the Doty study were similar overall to our subjects: the majority were college students (at the University of Pennsylvania), in good health and with no apparent olfactory problems. The main differences were that their study included 19% smokers (but only 4% smoked more than a pack per day) and that they were approximately 5 years older than our subjects (mean age 24.87, SD = 5.52, range 18–40 years).

The 36 odor stimuli were divided into 6 groups of 6 odors, such that each group had roughly comparable means and ranges on both familiarity and pleasantness, based on the normed ratings (see Table 1). Having these 6 odor sets (A–F) enabled the construction of 12 different lists such that across these lists, each of the 6 odor sets was used equally often in each of the 3 encoding conditions (familiarity, pleasantness, or double study). As shown in Table 2, sets A, B, and C were used as studied odors for one half of these lists, whereas sets D, E, and F were used as studied odors for the other half of these lists. Moreover, across the six lists using sets A, B, and C as studied odors, each of these three odor sets was used twice in the familiarity block only, twice in the pleasantness block only, and twice in both blocks. The same counterbalancing scheme was applied to the six lists using sets D, E, and F as studied odors. Each participant was given 12 stimuli in the familiarity block, 6 of which would be included in the pleasantness block; and 12 stimuli in the pleasantness block, 6 of which had been in the familiarity block. This resulted in 24 total encoding trials, encompassing 18 unique odors (with 6 odors in each of the 3 encoding conditions). The test block always included all 6 odor sets and thus 36 total stimuli. For each of the 12 different lists, the order of the odors was randomized within each encoding block and within the test block, and each of the randomizations was used to set up the stimulus materials for 2 participants.

The odor stimuli were placed on strips of numbered tickets in the preplanned order of presentation. Only the

Table 1 Subsets of odor stimuli

Group	Familiarity		Pleasantness	
	$\bar{x}$	*SD*	$\bar{x}$	*SD*
A	6.61	1.06	0.18	1.39
B	6.25	0.86	0.47	0.92
C	6.49	1.06	0.30	1.54
D	6.10	0.91	0.18	1.26
E	6.36	1.01	0.47	1.93
F	5.92	0.64	−0.31	1.39

Each of the above six sets (A–F) contained six odors. Each set of odors was formed based on comparable means and standard deviations for familiarity and pleasantness from a prior norming study (Doty et al. 1984, Fig. 2). The rating data were both based on nine-point scales, but pleasantness was represented with a central 0 point. The standard names of the odors were: (A) Banana, Bubble gum, Gasoline, Pine, Turpentine, Wintergreen; (B) Cedar, Clove, Dill Pickle, Rose, Soap, Watermelon; (C) Cherry, Coconut, Licorice, Menthol, Onion, Peach; (D) Chocolate, Grass, Leather, Mint, Pineapple, Smoke; (E) Grape, Lilac, Natural gas, Orange, Paint thinner, Strawberry; (F) Cinnamon, Gingerbread, Motor oil, Peanut, Pizza, Root beer.

Table 2 Counterbalanced odor lists

Encoding block 1	A B	A C	B A	B C	C A	C B	D E	D F	E D	E F	F D	F E	Familiarity
Encoding block 2	A C	A B	B C	B A	C B	C A	D F	D E	E F	E D	F E	F D	Pleasantness
Test block	A B C D E F	A B C D E F	A B C D E F	A B C D E F	A B C D E F	A B C D E F	A B C D E F	A B C D E F	A B C D E F	A B C D E F	A B C D E F	A B C D E F	Recognition memory

Each column represents 1 of 12 lists comprising the odor stimuli presented for familiarity rating (encoding block 1) and for pleasantness rating (encoding block 2), as well as the recognition-test stimuli (test block). Each of these 12 lists was used for two participants.

experimenter had access to the information matching the ticket numbers to odors. The numbered tickets were given, one at a time, to participants for scratching, sniffing, rating, and yes/no recognition testing.

Experimental procedure

In the study phase, participants were presented with 24 microencapsulated odor stimuli on numbered tickets in 2 study blocks of 12 items each. The familiarity block always preceded the pleasantness block, because prior exposure to half of the odors for pleasantness ratings could have increased their familiarity, thereby confounding subsequent familiarity ratings. Subjects were instructed to use the provided pencil to scratch each odor stimulus and then to smell it. In addition, they were asked to rate each odor stimulus on familiarity or pleasantness using a seven-point scale. The scale ranged from 1 being very unfamiliar or unpleasant to 7 being very familiar or pleasant; these ratings served as encoding/elaboration tasks. The study trials were not referred to as such when instructing the participants; moreover, participants were not informed that there would be a later recognition test (to minimize covert labeling and other intentional memory strategies).

Following the study blocks, participants engaged in a 20-min distractor task, Sudoku puzzles, a nonverbal problem-solving activity intended to distract participants from thinking about the previously presented odors. Participants were offered four levels of Sudoku difficulty ranging from beginner to expert.

Next, the participants were presented with an odor recognition test, in which there were 36 total odor stimuli, including 18 previously studied and 18 new odor stimuli. For the recognition test, they specified one of the following four options for each odor: (1) I did smell this earlier and I DID have a label for it; (2) I did smell this earlier and I did NOT have a label for it; (3) I did NOT smell this earlier, but I DO have a label for it; (4) I did NOT smell this earlier, and I do NOT have a label for it. Whenever they chose an option in which they had a label for the odor, they provided the label, which was transcribed by the experimenter.

Results

For each of the three encoding conditions (pleasantness, familiarity, and repeated encoding) each participant's hit rate was calculated, consisting of the proportion of the six previously rated odors to which the participant correctly specified "I did smell this earlier" during the recognition test. A single false-alarm rate was calculated consisting of the proportion of the 18 new odors to which the participant mistakenly replied "I did smell this earlier" during the recognition test. The hit and false-alarm rates were then utilized in the computation of d' scores for each participant, in each encoding condition. Discriminability (d') is a measure of sensitivity in signal detection theory; McNicol (2005) provides a detailed guide. Table 3 shows the means and standard deviations for the hit rates, the false-alarm rate, and the d' values. A one-way ANOVA with three levels representing the encoding conditions was computed using the d' data, $F(2,46) = 5.12$, $P = 0.010$. Planned comparisons revealed that the mean d' for recognition was greater for repeated encoding than for single encoding, $F(1,46) = 9.37$, $P = 0.004$, and that the means for familiarity-only and pleasantness-only encoding did not differ, $F(1,46) < 1$. These results support the hypothesis that recognition discriminability is improved when odors are presented on two study trials versus one, but fail to support the hypothesis that recognition performance is affected differently by the study tasks used here (rating familiarity vs. rating pleasantness).

Next we turned to our secondary objective of whether degree of odor familiarity or pleasantness affects recognition memory performance. We used two independent sets of ratings for this purpose: the norms we reconstructed from Figure 2 of Doty et al. (1984), and the mean ratings from the current subjects made during the study phase. Using each set of ratings separately, we partitioned the 36 stimuli alternately into "higher than median" and "lower than median" subsets of opposite polarity for familiarity and pleasantness and computed d' for each subject's recognition performance in each cell. The means and standard errors are displayed in Figure 1. We performed a series of four parallel 2 × 2 (Encoding [single, repeated] × Polarity [unpleasant/unfamiliar, pleasant/familiar]) ANOVAs on d' for these partitions of the data, the results of which are in Table 4. In concordance with the previous analysis and as can clearly be seen in Figure 1, the main effect of single versus repeated encoding was significant in each ANOVA. For pleasantness, the main effect of polarity was significant for both sets of ratings. From inspection of Figure 1, it is apparent that this result is due to much stronger overall recognition memory for relatively unpleasant than for relatively pleasant odors. However, the interaction of polarity with number of

Table 3 Summary data for hit rates, false-alarm rate, and d' values

	Hits			False alarms	d'		
	Familiarity	Pleasantness	Both		Familiarity	Pleasantness	Both
Mean	0.75	0.72	0.81	0.39	2.15	1.48	3.72
SD	0.19	0.17	0.20	0.19	2.81	2.27	3.77

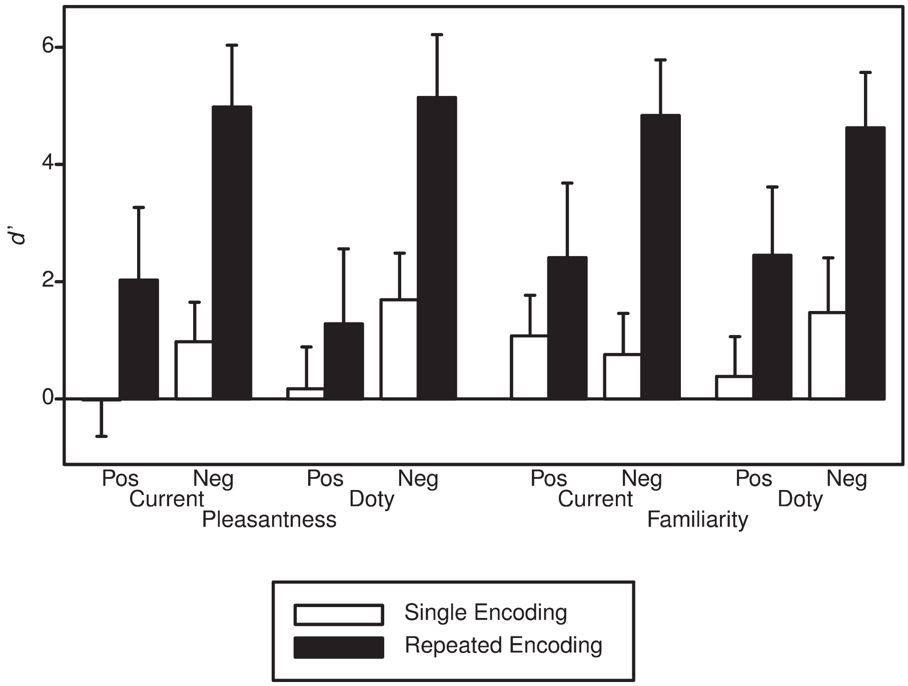

Figure 1 Means and standard errors of odor recognition discriminability (*d′*) after single versus repeated encoding trials, plotted with odor stimuli partitioned at the median into subsets of opposite polarity for Pleasantness and Familiarity (Pos: pleasant or familiar, Neg: unpleasant or unfamiliar), based on (Current) ratings from subjects in the current experiment or (Doty) published norms (Doty et al. 1984).

Table 4 Results of four analyses of variance on mean *d′* values for odor stimuli partitioned at the median for two quality ratings (pleasantness and familiarity) from two sources: Current experimental study phase and Figure 2 of Doty et al. (1984).

	Pleasantness				Familiarity			
	Current		Doty		Current		Doty	
	F(1,23)	P	F(1,23)	P	F(1,23)	P	F(1,23)	P
Encoding	14.8	0.001	7.64	0.011	9.98	0.005	16.0	<0.001
Polarity	4.64	0.040	8.38	0.008	1.40	0.247	3.77	0.062
Encoding × Polarity	2.37	0.134	2.70	0.110	2.94	0.096	0.583	0.541

Encoding: single versus repeated; polarity: pleasant or familiar versus unpleasant or unfamiliar.

encodings did not approach significance for either set of ratings. It is noteworthy that *d′* in both relatively pleasant partitions was very close to 0 after a single encoding, indicating performance at the chance level. For familiarity, there was no significant difference in overall recognition for unfamiliar than for familiar odors, although for the Doty norms, this difference approached significance, with relatively unfamiliar odors showing better overall recognition performance than relatively familiar odors. The interaction of familiarity with number of encodings was not significant for either set of ratings; however, it approached significance for the ratings from subjects in this experiment. From inspection of Figure 1, this appears to result from there being little difference in recognition performance for relatively unfamiliar versus familiar odors after a single encoding, but a larger difference after repeated encoding. In all 4 analyses, there is a numerically larger increase in *d′* from 1 to 2 encoding trials for low pleasantness and low familiarity than for high pleasantness and high familiarity, although this pattern was not reflected by significant interaction terms from the ANOVAs.

In addition to the previously mentioned strong correlation between the familiarity and pleasantness in ratings reconstructed from Figure 2 of Doty et al. (1984), this study's familiarity and pleasantness ratings were (by a curious coincidence) equally correlated, $r = 0.69$, $P < 0.001$. Furthermore, Doty et al.'s familiarity and pleasantness were correlated with those of the present experiment: $r = 0.46$, $P = 0.004$ and $r = 0.78$, $P < 0.001$, respectively. Given this strong correlation between familiarity and pleasantness ratings, it is not surprising that the pattern of results for familiarity and pleasantness is similar in terms of their effects on recognition performance. The strong correlations between the normed ratings and the ratings made in this study suggest that the microencapsulated stimuli have remained perceptually constant—at least in terms of those two qualities—since 1984, and that our subjects made their ratings with more or less the same rigor and on the same basis as the subjects of Doty et al. (1984).

We now turn to the association between hit rates and retrospectively reported covert odor labeling across the 36 odors used in this experiment. In this analysis, it was not relevant whether the covertly generated labels matched or did not match the manufacturer's labels. Using a *t*-test, we compared the frequency for which a verbal label was recollected for hits (correctly accepted previously presented odors; 61.5%) versus false alarms (incorrectly accepted distractors; 46.9%). The results indicate that covert verbal labels were recollected significantly more often for hits than for false alarms, $t(23) = 2.73$, $P = 0.011$. This result supports the hypothesis that covert verbal labeling played a role in the odor recognition performance.

Finally, we had hypothesized that subjects for whom olfaction was relatively more important in daily life might process studied odors more deeply and possibly show some benefit as a result of greater depth of processing. However, correlations between AIO scores and recognition d' did not support this hypothesis in any encoding condition: familiarity-only, $r = -0.33$, $P = .100$; pleasantness-only, $r = 0.12$, $P = 0.574$; repeated encoding, $r = -0.19$, $P = 0.637$; collapsed across encoding conditions, $r = 0.20$, $P = 0.652$. There was also a very low correlation between AIO and the number of labels covertly generated for studied odors, $r = -0.02$, $P = 0.911$. Taken together, these low correlations are contrary to the hypothesis that there is a relation between the importance of odors in daily life and odor recognition memory performance.

Discussion

One versus two study presentations and recognition memory

The study phase of this odor recognition memory experiment consisted of a block of familiarity ratings followed by a block of pleasantness ratings. Discriminability (d') was significantly higher for odors included in both blocks (repeated encoding) than for odors included in only 1 block (single encoding), supporting the hypothesis that multiple encoding/study trials enhance odor recognition. This result is consistent with those from previous word recognition memory studies that had compared multiple to single-study trials (Kelley and Wixted 2001; Jones 2005). Regarding odor stimuli, this result is consistent with the facilitation of odor recognition for multiple versus single exposures reported by Jehl et al. (1995); however, it contradicts Jehl et al. (1997), who reported interference with recognition memory for odors for which there had been multiple previous exposures. There are at least two ways that the double-study condition could have produced improved performance as compared with that of the single-study condition: by doubling the overall exposure time to the odors, and by doubling the types of processing required of the odors. According to the dual-process model of recognition memory, recollection and familiarity are two relatively independent processes that influence recognition memory (Hay and Jacoby 1999; Yonelinas 2002). Recollection is described as a relatively slow and deliberate process that involves memory access for the desired episode (in this case, smelling and rating the odor during the study phase) in conjunction with information concerning the context in which the episode was experienced (e.g., an emotion, feeling, or childhood memory brought to mind when smelling the odor). Familiarity, in contrast, is said to be a relatively automatic process that provides a quick indication of the strength of the memory for the episode, without any link to the context in which it was experienced. It should be noted that in a recognition memory experiment involving colored pictures, Opitz (2010) found that when the context varied between study repetitions, the familiarity-based process became dominant. In the present experiment, the two study trials involved different tasks (familiarity vs. pleasantness rating). Therefore, to the extent that these tasks constituted different encoding contexts, the improvement in recognition for repeated versus single encoding may have been due primarily to an increase in familiarity.

Doubling the exposure time may have increased the familiarity of odors in the repeated encoding condition, while doubling the number of types of processing may have increased the likelihood of retrieving a distinct, specific episodic context or semantic connection for those odors. However, in addition to these episodic and semantic memory processes, processes specific to odor sensory memory (Stevenson 2001) could have affected the outcome. Increases in exposure time have been shown to result in enhancement of perceptual discrimination, as well as increases in functional magnetic resonance imaging–assessed activation in several areas of olfactory cortex (Li et al. 2006; Gottfried 2008). In the present recognition memory study, as well as in the just-mentioned perceptual discrimination research, the increased study or exposure time occurred in the absence of any expectation by subjects that they would later be tested on the odors they were exposed to. In any case, it seems reasonable to assume that increased time and/or distinctiveness of odor encoding (even in an incidental learning situation) could contribute to enhanced odor recognition memory performance, as obtained here for the double-study condition.

The two single-study conditions (familiarity vs. pleasantness ratings) yielded equivalent levels of recognition performance. The encoding time was approximately the same for the two tasks, leading to no expected difference in increased familiarity. Therefore, the lack of a difference in recognition performance suggests that the demands of these two tasks produced equivalently memorable episodic memory and odor sensory memory effects.

Familiarity and pleasantness and odor recognition memory

Stimuli in this study represented a range of familiarity and pleasantness, based on published norms (Doty et al. 1984), although of course they are all sufficiently familiar that they are used in a standard clinical odor identification test. The ratings made by the subjects in the present study correlated very well with the published norms, and in addition, for both the norms and for this study, familiarity ratings were highly correlated with pleasantness ratings.

We found strong support for the hypothesis that there is better recognition performance with relatively less pleasant odors, based on previously published norms for pleasantness (Doty et al. 1984), as well as on ratings from this study. This result is consistent with Larsson et al. (2009), who also found a strong recognition advantage for unpleasant odors. Our results extend those of Larsson et al. in several ways. First, our odor stimuli were most likely more familiar to our subjects than theirs were to their subjects, since they chose low-familiarity odors to avoid odor identifiability cues. Our results confirm that the recognition memory advantage for unpleasant versus pleasant odors also occurs when they are relatively familiar and identifiable. The second extension is that the Larrson et al. study used only intraexperimental pleasantness ratings rather than both pre-experimental (Doty et al. 1984) and intraexperimental pleasantness ratings, as we did. Our utilization of the Doty norms allowed us to balance both studied and distractor items in terms of pleasantness (and familiarity), as part of the experimental design; this is in contrast to the Larrson et al. approach, whereby pleasantness ratings were obtained as a second dependent variable during the study. Our results indicate that employing pre-experimental odor quality ratings of standardized stimuli as independent variables can be useful, at least in this kind of recognition memory experiment. The objection could be raised that because of possibly large individual differences, neither cross-group or intra-group ratings are optimally applicable to any individual subject; however, the alternative of using each individual's own ratings is of limited utility in this experimental context because any preliminary rating trial would constitute an additional encoding trial. A third extension to Larsson et al. was that their subjects were instructed not only to memorize the studied odors, but also to name them overtly. In our study phase, subjects were instructed only to rate the odors, and were not asked to provide labels for them. Our results show that good recognition of odors can result from incidental learning alone, with no support from instructions to memorize or to verbally label the study stimuli. However, a very interesting and unanticipated result in this study was that there was virtually no evidence of learning to recognize relatively pleasant odors after a single encoding trial.

Regarding familiarity, as reviewed earlier more familiar odors have shown an advantage over less familiar odors in a number of recognition memory studies; however, many of these studies used samples of generally unfamiliar odors (e.g., Larsson et al. 2006). Given that our odor stimuli were generally familiar (i.e., taken from a standardized, clinical odor identification test), and given the well-known advantage in word recognition for low versus high familiarity/frequency (Yonelinas 2002), we did not have a specific hypothesis for the effect of high versus low familiarity for this study. The analysis based on the Doty norms, but not the ratings from the current subjects, shows a tendency ($P = 0.062$) for relatively less familiar odors to be recognized better than more familiar ones. Although this is not conclusive, it does not permit the exclusion of the hypothesis of a low-familiarity advantage, and it goes against prior reports of intraexperimental ratings of familiarity being positively correlated with hit rate (Murphy et al. 1991; Larsson and Bäckman 1993, 1997), as well as prior reports of improved recognition performance for a pre-experimentally selected set of familiar odors compared to unfamiliar odors (Öberg et al. 2002; Larsson et al. 2006). On the other hand, this tendency is consistent with the non-olfactory literature, which generally reports a low-familiarity recognition memory advantage (Mandler et al. 1982; Yonelinas 2002; Karlsen and Snodgrass 2004). Furthermore, the explanation suggested by Larsson et al. (2006) for a high-familiarity advantage was based on the lack of semantic and contextual information available for unfamiliar odors. As mentioned above, while our odor stimuli represented a range of familiarity, all were familiar enough to be part of a standard clinical odor identification test. Therefore, it is likely that there was more semantic and contextual information available for our unfamiliar stimuli than there was in prior studies that found a recognition advantage for familiar odors. Finally, it is not altogether surprising that familiarity and pleasantness ratings have a parallel effect on recognition memory performance, since the two qualities were highly correlated both in the norms of Doty et al. (1984) and in this study.

The analysis of the effect of low versus high pleasantness and familiarity on odor recognition memory also suggests the possibility that the effect of repeated encoding is larger for low-pleasantness odors (and perhaps also for low-familiarity odors). One possible explanation for this, along with the previously mentioned absence of recognition memory after a single encoding for pleasant odors, is that the rate of learning may be greater for unpleasant (and possibly unfamiliar) odors. This faster rate not only results in greater recognition after a single exposure, but also in increasingly greater recognition as exposure increases, presumably until some asymptote is reached. It could be that the rate of learning may be so slow for relatively pleasant odors, that no effect is produced until after a second encoding (or perhaps a longer initial encoding).

Subject factors: AIO and covert labeling

We also examined two factors having to do with subject characteristics and how they approached the study tasks as to their effects on recognition memory performance: the importance of odor in everyday life as measured by the AIO test; and the number of retrospectively reported, covertly generated verbal labels on studied items.

We had hypothesized that subjects for whom odor was relatively important in daily life might process odors more deeply during the study phase, and if so, might receive an advantage in recognition performance. Our results showed no such effect, suggesting that at least in the context of incidental learning of odors, individuals for whom odor is relatively important either do not process odors more deeply when exposed to them, or do not receive a recognition memory advantage from this processing.

Because it is well known that verbal labeling of odors can play a role in odor recognition memory, we designed our study so that no overt labeling was requested at the time of study. However, when we asked subjects during the test phase to indicate for odors they classified as "old" whether they recollected a label coming to mind during study, they responded in the affirmative significantly more often when the odor had in fact been presented earlier than if it had not. This indicates that, as we hypothesized and in accordance with Schab (1991), subjects covertly generate labels even in an incidental learning context, and reported labeling was associated more with hits than it was with false alarms. That is, it is likely that covertly generated verbal labels facilitated correct recognition of odors in this experiment.

Conclusions and future directions

This study found a significant improvement in odor recognition performance for odors encoded on two occasions versus one occasion. This result suggests that additional encoding time, possibly with increased distinctiveness of encoding (e.g., a greater variety of features being encoded across study trials), enhances odor recognition memory similar to how these factors have been shown to enhance recognition memory for other types of stimuli, such as words and pictured objects (e.g., Eysenck and Eysenck 1980; Dosher 1984; McAuliffe and Knowlton 2009). Future research will be required to ascertain the role of olfactory-specific odor sensory memory processes (Stevenson 2001). For example, one could compare single versus double study as in the present experiment, but with only very familiar odors for which such processes would play only a minimal role. Another possibility would be to use a much longer series of short repeated study trials with both olfactory and non-olfactory stimuli and then to compare the shape of the resultant learning curves, assessing differences in slope and asymptote as a function of sensory modality.

We also obtained improved recognition memory performance for less pleasant compared to more pleasant odors, in agreement with, and extending in several ways, the results of Larsson et al. (2009). Moreover, we found a tendency for better performance for less familiar versus more familiar odors, in contrast to positive correlations with familiarity reported by other authors. These findings provide significant new information about odor recognition memory, but leave several questions unanswered. For example, future research is needed to address the difference between familiarity and novelty of odors. Odor sensory memory processes that sharpen the discrimination of novel odors with increasing exposure are presumably not identical to the processes of familiarity that are known to be associated with episodic and semantic memory. For example, if a recognition memory experiment such as the present one were carried out with three levels of familiarity—completely novel, relatively unfamiliar, relatively familiar—then it could be that the best recognition performance would occur with relatively unfamiliar odors rather than completely novel odors, for the reasons suggested by Larsson et al. (2006), which were based on the absence of semantic and contextual information for novel odors.

Our results also suggest the intriguing possibility that less pleasant (and possibly less familiar) odors are learned faster than more pleasant or more familiar ones, and that this could underlie not only the improved overall recognition performance for less pleasant (and possibly less familiar) odors, but could also make predictions regarding the slope of the learning curve (that is, a steeper slope for less pleasant, less familiar odors). Although the interaction of encoding (one vs. two study trials) × polarity (high vs. low pleasantness; high vs. low familiarity) did not reach significance, we feel that future research on this question may be merited not only to verify the effect, but also to examine its implications. For example, research similar to the studies done on what was known as the "total time" hypothesis in the verbal learning literature (Cooper and Pantle 1967) could be carried out to tease apart the effects of repeated encoding from the effect of total exposure time, using different levels of odor pleasantness and familiarity.

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