Odor discrimination and recognition memory as a function of familiarization

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The role of olfactory familiarization in short-term recognition of odors was investigated. Subjects were asked to make qualitative similarity judgments regarding either identical or dissimilar odors delivered in pairs. Except for control groups, subjects got familiarized with either the first (target) or the second (distractor) or both odors from a pair. Groups also differed according to the number of familiarization sessions—one, two, or three—taking place prior to the discrimination judgments. There was no significant influence of familiarization on correct recognition scores for pairs of identical odors. The most salient finding was a marked decrease of false alarms as a function of the number of familiarization sessions, which evidenced a positive effect of familiarization on discrimination for pairs of dissimilar odors. These judgments were not dependent on an intensity criterion. False alarms did not vary according to whether subjects had been familiarized with the target or the distractor or both odors from a pair. A positive correlation found between discrimination performances and the number of odors correctly remembered as being presented during familiarization suggested that familiarization resulted in long-term storing of memory traces for familiarized odors. Since familiarization was effective despite conditions unfavorable to the use of semantic encoding, the results argue in favor of a predominantly perceptual encoding of odors in the investigated task.

In the olfactory domain, several studies have been carried out in order to investigate the encoding of odors in memory structures (Engen & Ross, 1973; Eskenazi, Cain, & Friend, 1986; Lawless, 1978; Lyman & McDaniel, 1986, 1990; Murphy, Cain, Gilmore, & Skinner, 1991; Rabin, 1988; Rabin & Cain, 1984; Schab, 1990). Some of these studies have indicated that the familiarity of subjects with the tested odors seems to be a determinant variable in a type of experimental procedure developed in order to evaluate olfactory memory in terms of odor recognition (Cain, 1984; Rabin & Cain, 1984). In principle, this procedure consists of presenting subjects with odors throughout the first part of the experiment, and then presenting the same subjects with the same odors, called targets, interspersed with other ones, called distractors, during the second part of the experiment. Hence, the task consists of recognizing, among the distractors, the target odors that have initially been delivered during the first part.

The influence of familiarity is expressed by an increase in performance, which depends on subjects' experience with the tested odors before the experiment has even begun. To study the effect of subjects' prior experience with tested odors, Rabin (1988) examined the ability of subjects to discriminate odors—that is, to recognize the odors as being the same or different when they are presented in pairs after having been learned. Rabin observed

that subjects who became familiarized with tested odors prior to the discrimination trials exhibited higher discrimination than did those who did not benefit from such a familiarization procedure. However, it must be noted that the learning of odors also entailed the training to name them. Hence, one is faced with the question of whether the mere perceptual experience with odors without any deliberate activity of verbal labeling can by itself enhance odor recognition performance. This question is worth considering with regard to the debate on the nature of odor encoding. If only the training to associate verbal marks with sensory attributes of odors has a positive consequence on recognition memory, the hypothesis of an analytic/semantic encoding of odors is thereby reinforced. Otherwise, if familiarization alone with no instruction to associate verbal labels with odors induces positive effects, the hypothesis of a holistic encoding remains plausible.

In the present study, we investigated the influence of familiarization on olfactory recognition by using a discrimination task with odors presented in pairs. We built a protocol in which subjects became experimentally familiarized with the tested odors. For this purpose, we used relatively unfamiliar odors—that is, odors that we assumed would not be well known from subjects' previous experience and that could therefore be the object of a graded familiarization procedure over several sessions. These odors of low initial familiarity offered the advantage of not spontaneously evoking the names of their sources, even though it was not possible to exclude that the subjects might perform some semantic processing on them. They had also to be of near neutral pleasantness, because even uncommon odors when put together can be distinguished on the basis

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of their hedonic tones without any preliminary learning (Schiffman, Robinson, & Erickson, 1975). Besides, the subjects were not prompted either to generate evocations about odors or to associate a verbal mark with their perception.

METHOD

Subjects

One hundred and ten young adults between 19 and 30 years of age ($M = 23.63 \pm 2.78$) volunteered for participation in this experiment. None had previously taken part in an olfactory design. None smoked. All were students, except a few who were researchers from biological laboratories. None presented anosmia to stimuli used in the experiment. They were paid for their time.

Stimuli

The odor set was made of 30 simple pure aliphatic and aromatic compounds selected to represent low initial familiarity, near neutral pleasantness, and diversity in odor qualities (Table 1). The odors were of moderate intensity for reducing the risk of adaptation across them while delivered. The odor samples were contained in 120-ml opaque glass jars to prevent subjects from visually identifying them. Each jar contained a 10-ml solution. To avoid discrimination based on intensity cues, both odors of a pair were matched for approximately equal subjective intensity by using another control group of subjects. This was done by using different dilution ratios ranging from 10^{-1} to 10^{-3} M. Mineral oil served as the solvent for the dilutions. The choice of the best value of the grade of odor dilution was made after approximately several tens of trials.

Experimental Design

Subjects were randomly distributed across 11 groups (Figure 1). Each group included 10 subjects balanced for gender (5 women, 5 men). The groups differed primarily in number of familiarization sessions with odors (from zero to three). We assumed that three learning sessions would induce some perceptible enhancement in subjects' discrimination abilities in comparison with those of subjects who had benefited from only one session. In two control groups ($F0_1$ and $F0_2$), subjects attended no familiarization sessions and performed only the discrimination test. The $F0_1$ and $F0_2$ groups were

distinguished from each other by the reversed order of presentation of the two odors of each pair (e.g., camphor–cineole for $F0_1$ and cineole–camphor for $F0_2$). This was done in order to test for the influence of the interaction between the two odors of a pair upon their discrimination. The nine familiarized groups were distinguished by two criteria: The first was the number (1, 2, or 3) of familiarization sessions (F); the second criterion was chosen according to whether subjects had been familiarized with the target (T), distractor (D), or target and distractor (TD) odors by means of the learning procedure (familiarization type). Groups familiarized with T or D odors were presented with 20 odors, whereas TD groups were presented with 30 odors (10 targets and 10 distractors from the different odor pairs, and only 10 odors from the identical odor pairs), and their familiarization session was longer. The same order of odor presentations was kept for subjects of Experimental Groups $F1$, $F2$, and $F3$ and those of Control Group $F0_1$.

Procedure

The experimental procedure comprised two parts (Figure 1). The first part was designed to train subjects to learn the odor samples perceptually (familiarization sessions). The second was aimed at assessing subjects' discrimination abilities after perceptual learning (discrimination test).

Familiarization session. A familiarization session consisted of presenting 20 odors (T and D groups) or 30 odors (TD groups). The odors followed each other in random order, one at a time during delivery. They were separated from each other by an interstimulus interval of 90 sec, sufficient to prevent subjects from sensory adaptation across the odors (Berglund & Engen, 1993; Duchamp-Viret, Duchamp, & Vigouroux, 1989; Sicard & Holley, 1984; Van As, Kauer, Menco, & Köster, 1985). This order was modified from one session to the next, so that subjects had no possibility to learn the odors from their rank order. However, within each session, this order was the same for all subjects. Inspection of the odor sample lasted 4 sec. The subjects were asked to remain silent during smelling. After inspection, they gave the jar containing the odor back to the experimenter. For groups that received more than one familiarization session, successive sessions were separated by 24 h. The subjects were told that they would participate in a test session, but they were not informed about its content.

Discrimination test. The subjects went on to the second part of the experiment 24 h later. For each individual, the time of testing was

Table 1
List of Odor Pairs Presented During Discrimination Test

Pairs		Odor		Order of Presentation
		First	Second	
Identical	1	coumarin	coumarin	4
	2	benzophenone	benzophenone	7
	3	1,1,2,2-tetrabromoethane	1,1,2,2-tetrabromoethane	17
	4	thymol	thymol	8
	5	beta-phenylethanol	beta-phenylethanol	5
	6	fenchyl alcohol	fenchyl alcohol	1
	7	alpha-phenylethanol	alpha-phenylethanol	15
	8	3,3,5-trimethyl cyclohexanone	3,3,5-trimethyl cyclohexanone	12
	9	methyl heptyl ketone	methyl heptyl ketone	18
	10	<i>l</i> -menthone	<i>l</i> -menthone	16
Different	1	dextro-camphor	1,8 cineole	9
	2	iso-amyl acetate	ethyl butyl ketone	20
	3	dibutyl ketone	diamyl ketone	14
	4	anisole	acetophenone	10
	5	benzaldehyde	nitrobenzene	3
	6	<i>d</i> -limonene	para-cymene	11
	7	isoborneol	fenchone	13
	8	galaxolide	pentadecalactone	6
	9	citronellol	geraniol	2
	10	cyclopentanone	cycloheptanone	19

Figure 1. Diagrammatic illustration of the experimental procedure. Four conditions of familiarization (F0, F1, F2, F3) were performed which varied by the number (from 0 to 3) of odor familiarization sessions prior to the discrimination test. Subjects differed according to the type of the familiarized odors: Target (T), distractor (D), or both (TD). During discrimination testing, subjects were presented with odor pairs. For F0₁, F1, F2, and F3, the first delivered odor was the target and that delivered after was either the target again or the distractor. For F0₂, this order of presentation of odors was reversed. The interval between two familiarization sessions or between a familiarization session and the discrimination test was 24 h.

approximately the same as that of the familiarization sessions. The subjects were involved in a task requiring them to make a similarity judgment on each of 20 delivered odor pairs. After the delivery of each pair, the subjects had to decide whether or not the first odor (target odor) from a pair was identical to the second one (target or distractor odor). An interval of 20 sec separated the presentation of two odors of a pair. The duration of this interval was thought to be adequate, since it was long enough to have the distractor not adversely modified by sensory adaptation to the target and it was short enough to remain within the limits of short-term olfactory memory as previously explored (Jehl, Royet, & Holley, 1994). The presentation order of odor pairs was at random, but it was the same for all subjects. A brief rest of 2 min occurred between odor pair presentations. During this interval, subjects orally enounced their similarity judgments. They also stated whether they could remember which odor of the pair, if not both, had been presented during the first part of the experiment (familiarization sessions). Finally, subjects had to

judge the intensity similarity of the two odors of each pair: The subjective intensities of the two odors were rated as either identical or different. At the end of the task, the subjects were told the purpose of the experiment and given their score of correct judgments.

The subjects were requested to make qualitative similarity judgments on 10 pairs made of identical odors and 10 pairs made of different odors. The identical pairs served as controls. Paired presentations of the odors allowed the subjects to achieve a good measure of discrimination, especially when using odors of low discriminability—that is, those from the pairs of slight qualitative dissimilarity.

The subjects performed the experimental tasks in a well-ventilated and silent room. They were instructed to remain silent throughout all the familiarization sessions and during the interstimulus intervals of the test session, because if they talked, a semantic component would have been covertly added to the perceptual encoding.

RESULTS

Quantitative and Statistical Analyses

Recognition memory performance was assessed using parameters—hits and false alarms, discrimination and bias measures—issued from the signal detection theory (Banks, 1970; Lockhart & Murdock, 1970). To analyze memory data, general methods of single-, two-, and three-way analyses of variance (ANOVAs), with or without repeated measures, were used (Winer, 1962). Differences between pairs or groups of means were assessed in multiple orthogonal comparisons. The normality of the samples (except for the dichotomous data) and the homogeneity of their variance were controlled with the Lilliefors (Conover, 1971) and the Hartley (Winer, 1962) tests, respectively.

Recognition Performance as a Function of Familiarization

Figure 2 represents the arithmetic mean of hit scores, false alarm scores, discrimination and responses bias measures, respectively, as a function of the number of familiarization sessions (comparisons between F1, F2, and F3) and as a function of the type of familiarization (comparisons between familiarization with target odor, distractor odor, or both). Data from Control Group F0₁ are represented on the left of each graph. To analyze data with a balanced design, nine sets of data from F1, F2, and F3 were first analyzed with a two-way ANOVA. Second, the data from this control group were compared with the nine sets of data with the aid of a one-way ANOVA.

The two-way ANOVA revealed no reliable difference of hit scores between F1, F2, and F3 conditions [$F(2,81) = 3.01$, n.s.], no effect of type of familiarization [$F(2,81) = 1.70$, n.s.], and no interaction between number of sessions and type of familiarization [$F(4,81) = 1.52$, n.s.]. Furthermore, a one-way ANOVA and multiple orthogonal comparisons did not show significant variations of hit scores between the Control Group F0₁ and the nine familiarized groups.

For false alarm scores, the two-way ANOVA showed a highly significant effect of number of sessions [$F(2,81) = 36.88$, $p < .0005$], no effect of the type of familiarization [$F(2,81) = 3.72$, n.s.], and no interaction between both

Figure 2. Representation of hit scores, false alarm scores, discrimination measures and bias measures as a function of the four familiarization conditions (F0₁, F1, F2, F3) and as a function of the type of the familiarized odor (T, D, or TD) for each of these conditions. The vertical bars represent standard errors of the mean (SEM).

factors [$F(4,81) = 0.38$, n.s.]. Multiple orthogonal comparisons between mean blocks of different groups showed that the significant effect of the number-of-sessions factor was due to a significant decrease of false alarm scores from F1 to F2 [$F(1,81) = 34.00$, $p < .0005$] and from F2 to F3 [$F(1,81) = 6.47$, $p < .025$]. A one-way ANOVA and subsequent orthogonal contrasts revealed significant differences of false alarms between the Control Group (F0₁) and the respective means of F2 and F3 only [$.025 > p < .0005$].

For d' scores, the ANOVA indicated significant variations of discrimination performance between F1, F2, and F3 [$F(2,81) = 36.82$, $p < .0005$]. Neither the effect of familiarization type on d' scores [$F(2,81) = 1.06$, n.s.] nor the interaction of number of sessions and type factors were significant [$F(4,81) = 0.39$, n.s.]. Orthogonal comparisons of means revealed a significant increase in discrimination from F1 to F2 [$F(1,81) = 29.31$, $p < .0005$] and from F2 to F3 [$F(1,81) = 9.36$, $p < .005$]. A one-way ANOVA and subsequent mean comparisons revealed that

all means of F2 and F3 presented scores significantly higher than that for F0₁ [$.01 > p < .0005$].

Analysis of bias measures indicated no significant variations between the F1, F2, and F3 conditions [$F(2,81) = 2.94$, n.s.], significant differences as a function of familiarization type [$F(2,81) = 4.02$, $p = .025$], and no time $\times$ type interaction [$F(4,81) = 1.68$, n.s.]. Orthogonal comparisons of means showed a significantly higher score for subjects familiarized over 2 days (F2) with the target odor than for subjects familiarized with the distractor odor or for those familiarized with both odors [$F(1,81) = 7.08$, $p < .01$] and [$F(1,81) = 5.79$, $p < .025$], respectively. A one-way ANOVA and successive orthogonal comparisons showed that scores of subjects familiarized with the target odor over 2 days (F2) or 3 days (F3) were significantly higher than those of subjects (F0₁) not previously familiarized with any odor [$F(1,81) = 7.56$, $p < .01$] and [$F(1,81) = 4.84$, $p < .05$].

Finally, the scores of hits and false alarms observed in subjects of the two Control Groups (F0₁ and F0₂) were

subjected to a one-way ANOVA. They did not show significant differences between the two groups [hits, $F(1,18) = 0.00$, n.s.; false alarms, $F(1,18) = 0.07$, n.s.]. Thus the order of presentation of the two odors did not influence the olfactory performance.

Recognition Performance for Each Odor Pair

For each odor pair, the numbers of hits and false alarms were rated respectively as a function of the numbers of familiarization sessions (F1, F2, F3; first factor), the familiarization type (second factor), and the odor pairs (third factor), (Figure 3). A three-way ANOVA was performed with repeated measures on the last factor (pairs). The results of the ANOVA did not show signifi-

cant differences between the three conditions (F1, F2, and F3) or between the familiarization types on scores of correct recognition [$F(2,81) = 3.01$, and $F(2,81) = 1.70$, respectively]. A highly significant difference was observed as a function of odor pairs [$F(9,729) = 5.22$, $p < .0005$]. No interaction was significant. Significant orthogonal comparisons between pairs of means of the same second factor (T, D, or TD) showed that the differences were due to the lower number of correct recognitions recorded for pairs of identical odors: coumarin (Pair 1), beta-phenylethanol (Pair 5) and alpha-phenylethanol (Pair 7) in comparison with the number of correct recognitions for the other odor pairs, mainly when subjects were familiarized 1 day only (F1).

Figure 3. Frequency of hits (left) and false alarms (right) for each of 10 odor pairs according to the number of familiarization sessions (F1, F2, and F3) and the type of the familiarized odor (T, D, or TD).

The number of false alarms (Figure 3, right panels) differed significantly as a function of the number of familiarization sessions [$F(2,81) = 36.88, p < .0005$], familiarization type [$F(2,81) = 3.72, p < .05$], and odor pairs [$F(9,729) = 8.14, p < .0005$]. No significant interaction was observed. Multiple orthogonal contrasts mainly revealed a significant decrease of false alarm scores from F1 to F2 [$F(1,81) = 34.00, p < .0005$], from F2 to F3 [$F(1,81) = 6.47, p < .025$], and from F1 to F3 [$F(1,81) = 70.15, p < .0005$]. Significant orthogonal contrasts between pairs of means for each familiarization type factor (T, D, or TD) showed that significant differences were mainly observed when subjects were familiarized for 1 day (F1). They are due to the lower number of false alarms recorded for Pairs 4, 5, and 6 (anisole–acetophenone, benzaldehyde–nitrobenzene, and *d*-limonene–para-cymene) on the one hand, and to the higher number of false alarms recorded for Pairs 3 and 8 (dibutyl ketone–diamyl ketone, and galaxolide–pentadecalactone).

Intensive Similarity

Judgments of intensive similarity between the two odors of each pair were rated in two different situations:

when the two odors were identical or when they were different (Figure 4). In addition, judgments were represented for subjects (top panel) familiarized in different conditions regarding the duration of familiarization (F1, F2, F3) and the familiarization type (T, D, TD), and for control subjects, F0₁ and F0₂ (bottom panel). For the familiarized groups, a three-way ANOVA with repeated measures on the last factor revealed no significant variation of the intensity judgment as a function of the number of familiarization sessions (first factor) [$F(2,81) = 1.84, n.s.$], the familiarization type (second factor) [$F(2,81) = 0.26, n.s.$], or according to whether the two odors were identical or different (third factor) [$F(1,81) = 3.45, n.s.$]. For control groups, a two-way ANOVA also revealed no significant variation between F0₁ and F0₂ groups [$F(2,81) = 0.26, n.s.$] and no significant difference according to whether the two odors were identical or different [$F(2,81) = 0.26, n.s.$].

To investigate a possible influence of intensive similarity judgments on subjects' responses bearing on qualitative similarity, the results were compared for each kind of qualitative similarity judgments (correct and incorrect recognition; correct and incorrect rejection) (Table 2).

Figure 4. Frequency of identical intensive similarity judgments regarding odor pairs for the three familiarized conditions (F1, F2, F3, at the top) and the control conditions (F0₁ and F0₂, at the bottom) according to the type of the familiarized odor (T, D, or TD).

Table 2
Identical or Different Intensive Judgment as a Function of
Qualitative Similarity Judgment

Quantitative Summary					
Intensity Judgment	Odors				Total
	Identical		Different		
	Correct Recognition	Incorrect Rejection	Correct Rejection	Incorrect Recognition	
Identical	415	83	361	87	946
Different	442	160	496	156	1,254
Total	857	243	857	243	2,200

When the two odors of a pair were identical, the results showed that subjects more often incorrectly judged the odors as different if they had rated their intensities as being different (160 vs. 83). When the two odors were different, and their intensities were rated as being different, more correct rejections were found (496 vs. 361), but also more incorrect recognitions were observed (156 vs. 87). For each odor pair, the examination of scores revealed that

these variations were mainly due to the odor Pairs 1 and 5 (coumarin–coumarin and beta-phenylethanol–beta-phenylethanol) when the two odors were identical, and 3 and 8 (dibutyl ketone–diamyl ketone and galaxolide–pentadecalactone) when they were different. The judgments of intensive similarity adversely influenced those of qualitative similarity only in the case of the four odor pairs cited above in that the numbers of incorrect rejections and incorrect recognitions were increased.

Familiarization and Odor Remembrance

During the test session, after each trial, subjects were asked which odor had been presented on the previous day during familiarization sessions: The first odor of the pair, the second odor, or both. The number of odors remembered by 10 subjects were pooled across all pairs as a function of the qualitative similarities of odors in pairs (the two odors were either identical or different) (Figure 5). In each situation, three factors were considered: Data were represented as a function of the number of fa-

Figure 5. Frequency of correct recognitions of odors as a function of the number of familiarization sessions (F1, F2, F3) and the type of familiarization (T, D, TD) when the two odors of a pair were identical (at the top) and different (at the bottom). Subjects declared to recognize either the first odor (Odor 1) in a pair, or the second one (Odor 2) or both (Odors 1 and 2).

miliarization sessions (F1, F2, F3), the familiarization type (target, distractor, or target and distractor), and the memorized odor (first, second, or both).

When the two odors of a pair were identical, subjects systematically judged that they had smelled only the first odor during familiarization sessions. A three-way ANOVA indicated significant differences of the numbers of correctly remembered odors as a function of the number of familiarization sessions [$F(2,81) = 8.54, p < .0005$] and the nature of the memorized odor [$F(2,162) = 1,358.28, p < .0005$], but no significant variation as a function of the familiarization type [$F(2,81) = 0.47, n.s.$]. Interestingly, multiple orthogonal contrasts showed a significant increase of the number of odors recalled from F1 to F3 [$F(1,81) = 16.32, p < .0005$] and from F2 to F3 [$F(1,81) = 7.69, p < .01$]. Thus, the increase of the number of familiarization sessions with odors significantly increased the score of recalled odors.

When the two odors of a pair were different, the three ANOVAs revealed significant differences of the number of correctly remembered odors as a function of the number of familiarization sessions [$F(2,81) = 7.95, p < .001$], the familiarization type [$F(2,81) = 11.31, p < .0005$], and the nature of the memorized odor [$F(2,162) = 77.28, p < .0005$]. Orthogonal comparisons indicated significant increases in the number of correctly remembered odors from F1 to F2 [$F(1,81) = 4.52, p < .05$] and from F1 to F3 [$F(1,81) = 15.88, p < .0005$]. Thus, as for pairs of identical odors, the increase in the number of familiarization sessions with odors significantly increased the number of recalled odors. However, these results were only observed when subjects were familiarized with the target odor from F1 to F3 [$F(1,81) = 7.63, p < .01$], the distractor odor from F1 to F3 [$F(1,81) = 5.29, p < .025$], and from F2 to F3 [$F(1,81) = 5.29, p < .025$], and both odors from F1 to F2 [$F(1,81) = 4.62, p < .05$].

Recognition Performance and Memory

Correct recognition and rejection scores were correlated to the number of correctly remembered odors delivered during familiarization sessions. The computation of the correlation coefficient indicated that these two variables (recognition performance and recall performance) were slightly correlated ($r = .44$). The significance test permitted rejection of the null hypothesis [$t(88) = 4.56, p < .01$], and therefore acceptance of a significant correlation between recognition performance and recall performance.

DISCUSSION

This study highlights the effect of familiarization on short-term recognition memory for odors. However, this effect is not manifest when one considers correct recognition scores only; it becomes visible when false alarm scores are taken into account.

Olfactory Performances

Correct recognitions. The correct recognition results do not show any influence of the number of familiariza-

tion sessions on the qualitative similarity judgments on pairs of identical odors. At first examination, this may be interpreted as a "ceiling effect." The recognition task would be easy and optimally carried out without benefit from previous experience with odors. However, this interpretation must be revised in light of false alarm scores (see below).

The data from judgments of intensive similarity on these same odor pairs seem to indicate that the judgments of qualitative similarity are not seriously biased by an intensity criterion. The proportion of correct qualitative similarity judgments systematically exceeds that of correct judgments regarding similarity of intensity. This means that even though subjects erringly perceived odors as different in intensity, they more rightly recognized their similarity in terms of quality. This interpretation is in agreement with the conclusion of an earlier study by Engen and Pfaffman (1960), who showed that quality prevailed over intensity in an odor identification task.

The results of correct recognitions examined for each of the identical odor pairs make apparent differences that can be imputed to the nature of odors. As an example, despite an interindividual variability, all the groups familiarized with odors have their lowest scores of correct recognitions for coumarin, beta-phenylethanol, and alpha-phenylethanol, and their highest scores for benzophenone, methyl heptyl ketone, and *l*-menthone. The explanation for these variations is not clear. The order of odor presentation does not seem to have caused these variations. For example, coumarin and beta-phenylethanol, for which scores were low, were delivered at the beginning of the trials, when sensory fatigue was not supposed to be strong.

False alarms. Contrary to what has been observed for pairs of identical odors, performance bearing on pairs of qualitatively dissimilar odors is sensitive to the influence of the number of sessions of odor familiarization. The decrease of false alarm scores with the increase in the number of familiarization sessions expresses the positive influence of familiarization on olfactory discrimination. Our false alarm data are in accord with those of a previous study (Jehl et al., 1994) showing that the production of false alarms is dependent on the qualitative proximity between odors to be compared.

The absence of a strict correspondence, in terms of proportion, between the two classes of similarity judgments—regarding quality and intensity—points to the fact that the qualitative similarity judgments do not depend on those of similarity in intensity. Hence, the idea is reinforced that variations in false alarms are primarily linked to the familiarization factor. Aside from factors of familiarization and interindividual variability, false alarms vary also according to the nature of single chemicals composing odor pairs. Thus, a lower number of false alarms was found for anisole–acetophenone, benzaldehyde–nitrobenzene, and *d*-limonene–para-cymene, whereas a higher number of false alarms was found for dibutyl ketone–diamyl ketone and galaxolide–pentadecalactone than for the other pairs. These differences can be explained in terms of qualitative proximity. For example, the degree of qualitative proxim-

ity is higher for the pair dibutyl ketone–diamyl ketone than for that of anisole–acetophenone, and this results in a higher proportion of confusion between the odors of the former pair.

Discrimination and bias measures. As shown in an earlier work (Jehl et al., 1994), qualitative similarity judgments are strongly dependent on a decision criterion that introduces some bias in their cognitive basis. The decreased number of false alarms under lengthening of familiarization while correct recognition scores remained nearly stable resulted in an apparent change of the decision criterion adopted by subjects. Nonfamiliarized subjects adopted a liberal criterion while subjects becoming familiarized (F2, F3) manifested more conservative judgments. To explain this finding, one may hypothesize that, when comparing two odors, subjects were spontaneously more inclined to seek differences than to recognize similarities. This could be the reason why when judging pairs of slightly dissimilar odors—a difficult task in absence of familiarization—they declared the odors to be similar if they were not sure that their qualities were actually different. This resulted in a rather good correct recognition score at the cost of making a large number of false alarms. One may think that familiarization enabled subjects to discriminate the barely perceptible differences in odors of proximate qualities better, allowing them to reduce their false alarm scores, without significantly changing their hit scores. It seems as if they were more confident in their similarity ratings and their decision criterion shifted from liberal to conservative.

Memory Processes and the Criterion of Judgment

It appears that a major finding of our study is the influence of subjects' familiarization with odors on judgment criteria involved in odor recognition. A possible explanation of the influence of familiarization is the involvement of distinguishable memory processes for the familiarized and not familiarized odors. One of these would be a short-term memory process involved in the comparison between an odor (target or distractor) and the memory of another one presented 20 sec earlier. For the control groups with no benefit of familiarization, only the short-term memory was involved. One may assume that for the delay of 20 sec between odor presentations, the memory trace would fade, thereby losing precision. The bases of subjects' judgments were therefore insufficient, but subjects adopted a liberal criterion preferentially, assuming that both odors were identical in quality since they could not detect any clear indication of their differences. This resulted in a great number of correct recognitions but also of false alarms.

The second process would involve a long-term memory of familiarized odors subjected to a familiarization procedure. During a discrimination trial, this long-term memory would presumably be elicited by the presentation of a familiarized odor. Hence, this memory would be more precise and more stable than the short-term memory, especially after three familiarization sessions. Data on cor-

rect recalls of familiarized odors (Figure 6) also support this idea. For example, remembrance scores of F3 groups have a tendency to be both more numerous and more accurate than those of F1 groups. On the basis of the conjunction between short-term and long-term memories, subjects could form a more accurate representation of the reference odor and, consequently, could more rightly reject their implicit assumption of odor identity when the odors were actually different. This resulted in a decreased number of incorrect recognitions, which appears as the adoption of a more conservative criterion.

The fact that the manipulation of experimental variables affected the false alarm rate without changing the hit rate has already been reported in the literature on odor memory. For instance, Lyman and McDaniel (1986) studied the effects of various encoding tasks on long-term recognition of odors by instructing the subjects either to form visual images of the source of the odor, or to name the odor, or to describe a life episode of which the odor reminded them. They showed that the label and life episode groups performed significantly better than control or visual groups, but only through a reduction in the number of false alarms (36% and 45%, respectively). Hit rates remained stable for all experimental conditions (67.5% on the average). Hence, in conditions where discriminative indices are poor, subjects' judgments seem to be systematically biased toward the assumption of identity rather than the opposite assumption of difference. Further studies are needed to determine whether this strategy characterized discrimination judgments on odors, specifically, or resulted from particular experimental conditions.

Conclusions

The present results can be taken as confirming the role of perceptual encoding in the discrimination of low discernible and unfamiliar odors. Even if subjects could not be prevented from covertly associating names or evocations to odors and therefore semantically processing them to some extent, it seems that in the frame of our experimental conditions, verbal encoding played a minor role in the recorded performances. In our experiment, the facts that odors were chosen for low familiarity and subjects had no instructions to semantically process odors during familiarization and to memorize them until the second experimental part, leads to the conclusion that subjects' discrimination abilities were mainly based on a perceptual form of encoding achieved through familiarization.

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