Chem. Senses 24: 317–325, 1999

Odors: Implicit Memory and Performance Effects

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Abstract

In order to assess the influence of odors on human performance and implicit memory for odors, 108 subjects completed a variety of tests in weakly scented (jasmine, lavender or odorless) rooms without having been made aware of the odor. After a 30 min interval the subjects were shown slides of different surroundings, including the room they had been in, and were requested to rate how well a set of 12 odors, including a blank, would fit to these surroundings. Half of these contexts contained visual cues related to two of the presented odors (leather and coffee). After the rating of fit the subjects had to rate the odors for pleasantness, were asked to identify the odors with their correct names and to tell where and when they had last smelled these odors. One subject remembered smelling the odor (jasmine) in the room and was discarded from the analysis of the results for the rating of fit. None of the others reported recollection of the experimental odors. The results showed that in general jasmine had a negative and lavender a positive effect on test performance. If an odor-related visual cue was present in the context, the related odor was always rated highest in fit to that context. Furthermore, the subjects working in rooms with an odor subsequently assigned this odor to the visual context of that room to a significantly higher degree than subjects working in rooms with different odors. Since none of the subjects reported that they had smelled the odor in the rooms where performance testing took place, it was concluded that the memory for these odors was implicit. Further analysis showed that such memory was only found in subjects who were unable to supply the right name for the odor. The possible consequences of this latter finding for understanding the relationship between sensory (episodic) and semantic odor memory are discussed.

Introduction

Influence of odor on human behavior and implicit odor memory are both phenomena that are generally accepted, notwithstanding the lack of scientific proof regarding their existence. Although there is a wide belief in aromatherapy (Tisserand, 1995) and in the fact that aromas can somehow magically influence behavior in everyday life, there is only little systematic work on these issues compared with the amount of research for other modalities (Schacter, 1987; Smith, 1989). In studies of performance facilitation by ambient odors (Gilbert *et al.*, 1997) or by merely suggested ambient odors (Knasko *et al.*, 1990) no significant effects on performance measures like clerical coding or digit deletion tasks were found. In both studies the subjects knew about the nature of the research and were explicitly aware of the fact that the influence of ambient odors on subjects performance was examined. A study by Torii *et al.* (1988) showed the effects of several odors on 'contingent negative variation' (CNV) in the EEG. These effects were interpreted as stimulative or sedative respectively. Despite the fact that direct facilitation of performance as measured in reaction times was not found in this experiment, the assumption was made that a moderate increase in the degree of arousal caused by a stimulating odor could have a positive effect on performance rates, whereas a sedative reduction of arousal would have the inverse effect. This assumption was based on the Yerkes–Dodson law, which describes the relationship between arousal or vigilance and performance (Yerkes and Dodson, 1908; Wrisberg, 1994) as an inverted U curve. According to this law there is an optimal arousal level below and above which performance decreases. Below this optimum a stimulating odor would raise performance and a sedative odor would decrease it. Above the optimal arousal level (see later in discussion) these odors would have the opposite effects.

In research on implicit memory for odors, a clear and systematic proof for or against this form of human memory has not been produced so far. An experimental design used by Schab and Crowder (1995) showed 'implicit' effects in the olfactory modality at first, but was later unable to support these findings in subsequent experiments. Furthermore, just like in the experiments about performance cited above, the authors worked with explicitly or consciously presented odors in the learning phase of the experiments. Degel and Köster (1998) found evidence of implicitly learned memories for odors in an experiment in which they asked the subjects to rate how well odors fitted to visual contexts. In contrast to the work of Schab and Crowder (1995), the odors did not serve as explicit stimuli in the learning phase. However, some essential variables were not systematically

Table 1 Odors used in the rating of fit between odor and environment

Odor name	Description	Pleasantness[a]		Correct identification[b](%)
		Mean	SD	
Sandalwood	sandalwood odor	44.04	26.21	0.9
Ambient odor 2	woody ambient odor	31.36	25.36	0
Cedarwood	cedarwood odor	32.35	26.35	0
Laundry	similar to washing detergent	46.87	24.99	0.9
Jasmine	jasmine odor	34.51	27.54	0.9
Lavender	lavender odor	49.80	32.17	56.5
Coffee	coffee odor	47.08	34.06	77.8
Ambient odor 3	spicy ambient odor	54.09	23.89	0
Aftershave	similar to after-shave perfume	48.14	25.72	4.6
Leather	leather odor	35.10	27.87	47.2
Ambient odor 1	fruity ambient odor	53.61	24.46	0

[a]Pleasantness as judged by the subjects at the end of the experiment (maximum = 100).

[b]Correct identification of the odor at the end of the experiment.

controlled in this experiment, thus leaving room for objections to the interpretation of their results.

In order to both explore the role of odors in facilitation of performance and to show a systematic approach for detection of implicit memory in the olfactory modality this study extends the method suggested by Degel and Köster (1998). In the learning phase, subjects were submitted to several performance tests under different odor conditions, but without any information about the fact that odor was involved in the experiment. The tests were chosen to measure creativity, concentration and mathematical abilities. Thirty minutes later, the subjects were asked to rate the fit of several odors to different visual contexts, including the one in which they had just worked, in order to show implicit memory effects in the ratings. After this, the subjects had to rate the odors for pleasantness. Finally, in order to control for the absence of effects of conscious perception on the results for the rating of fit, they were asked to label the odors and to mention the place and time where they had last smelled the odor.

Based on the experiments by Torii *et al.* and by Degel *et al.*, there are two main hypotheses involved in the present study: subjects in a stimulating odor condition are expected to be more creative and productive, and to make less errors than those in the neutral or sedative odor condition. Also, if there is an influence of implicit memory for odors, the rating of the fit between odors and environments will be positively influenced by unconsciously or subliminally learned odors in the test rooms.

Materials and methods

Participants

A total of 108 subjects, 54 men (average age 29.8 years) and 54 women (average age 30.1 years), participated in the study. The subjects were recruited by telephone and were paid FF 150 for their participation. The subjects were randomly split into three equivalent groups (C, J, L) of 36 subjects consisting each of 18 male and 18 female subjects (average age group C: 30.2 years, average age group J: 30.4 years, average age group L: 29.2 years).

Odors

In the 'learning' phase jasmine and lavender were chosen as the odors in the experimental rooms. According to Torii *et al.* (1988), jasmine is supposed to be a stimulating and lavender a sedative odor. A non-odorized room served as the control condition.

In the 'rating of fit' phase, a set of 12 jars was presented, 11 of which contained an odor at an equalized supra-threshold concentration, the other containing no odor at all. Subjects were told that each jar contained an odor, although sometimes in such a weak concentration that they might not smell anything. To avoid visual interference (Davis, 1981; Zellner and Kautz, 1990) the jars were identical. They were marked with a randomly chosen three-digit code. The position of the jars for the rating of fit was balanced over all subjects.

The chosen odorants represented a variety of scents known from everyday life. Some of them were directly related to the visual cues shown in images of the rating of fit task, some had a perfume-like character and some (jasmine, lavender and no odor) had served as ambient odors in the testing rooms. Table 1 shows the odor qualities with a short description. Some of the results to be described later are also given in this table.

Visual materials

In the rating of fit phase, 12 pictures were used showing the

Table 2 Context sequence, context content and visual odor cue

Sequence	Context content	Visual odor cue
1	kitchen	coffee cup
2	larger train compartment	no cue
3	car dashboard	leather interior
4	testroom J	no cue
5	office	Coffee cup
6	train lavatory	no cue
7	small train compartment	coffee cup
8	testroom L	no cue
9	men's department	leather jackets
10	bank advisory room	no cue
11	canteen room	leather jacket
12	testroom C	no cue

three test rooms and different surroundings from everyday life. Three of them contained a visual cue for leather odor and three others contained a visual cue for coffee odor. The order of the pictures was kept constant over sessions. The sequence of the pictures was randomized with the restriction that pictures with and without a visual cue were alternated (see Table 2).

Test material

In order to assess the subjects' performance a creativity test, a letter counting concentration test and a mathematical test were used. The creativity test was based upon open-ended associative thinking (Wallach and Kogan, 1965; Wyon *et al.*, 1997), a task in which subjects had to specify as many instances of a given class of objects as they could think of. The classes of objects were (a) things that are red, (b) things that will make noise, (c) things that are square and (d) things that move on wheels. In the provided time for the creativity test (2 min) the subject was instructed to tell the interviewer as many instances of these object classes as possible. To keep the subject concentrated on the task and in order to avoid any confounding effects of differences in writing speed on the results, the interviewer wrote down all the specified instances.

In the letter counting concentration test the subjects had to count the frequency of a specified letter in 25 rows consisting of 50 randomly arranged mirror image letters (b, d, p, q) each. After counting and indicating the correct frequency of letters in a row the subjects were instructed to go to the next row. A total of 8 min was provided for this test. The mathematical test consisted out of five blocks of 15 tasks. In each block there were five multiplication tasks (multiply a single digit number by a double digit number), five addition tasks (add a double digit number to a double digit number) and another five subtraction tasks (subtract a double digit number from a double digit number). After completion of one block the subject was instructed to go to the next block of tasks. A total of 8 min was allowed for this test.

Each subject was instructed and tested individually by an interviewer. The sequence of the tests was not varied over the subjects and interviewers.

Procedure

All the subjects of one group were assigned for performance testing to a room that was scented with either an ambient odor [jasmine (group J) or lavender (group L)] or no odor [control (group C)] respectively. The subjects were not told that odors played a role in the study or that odors were present in the rooms.

The subjects participated individually. After meeting the interviewer, the subject was taken to the test room corresponding to the group he/she was assigned to and made to wait for 15 min before the interviewer started the tests. The interviewers were instructed to keep a rigorous time schedule and to start the next test as soon as the time for the previous test had elapsed. The total duration of the tests, including the initial 15 min waiting time and instructions, was 45 min.

In order to control for interviewer effects, the three interviewers were rotated systematically over the three experimental groups. Thus, each interviewer saw an equal number of men and women in each group and in each test room. Moreover the interviewers were kept unaware of the fact that the three rooms had different odors. They were also unaware of the aim of the study. After completion of the three tests, the subjects were taken to a different room where they took part in an experiment on the hedonic properties of three kinds of cookies, which lasted for 30 min. At the end of this experiment the subjects took part in the final stage of the experiments: the rating of the fit between odors and environments which took place in still another room. The subjects were seated in groups of three, separated by side walls, in front of a screen on which the visual images of the different contexts were projected. They each had the set of 12 odor jars in front of them. The subjects were instructed to rate how well each odor fitted each of the contexts shown. Ratings of fit were made on a 100 mm visual analog scale with the end labels 'does not fit' and 'fits'. After rating the fit of all odors to a visual context, a new context was shown on the screen. To neutralize the odor perception and cause a temporal delay between the ratings of fit the subjects were told to smell the inside of their own arm after each rating. In order to reduce olfactory adaptation a pause of 45 s was made before a new visual context was shown.

After completion of the rating of fit and a pause of 5 min the subjects had to rate the 12 odors for pleasantness, and were asked to write down the name of the odor and the place and time where and when they had last smelled the odor.

Statistical analysis

The analysis was performed with SPSS for Windows, Version 6.1.3 (SPSS, Inc., 1994).

For the letter counting and mathematical tests, measures of 'Amount' (rate of processed tasks per 100 test tasks) and 'Error' (rate of errors per 100 processed tasks) were calculated. The creativity score (C-score) was calculated according to Wyon *et al.* (1997). The score for having mentioned a given category was calculated in accordance to information theory as $\log_2(1/P)$ where P is the probability that the answer is given by a randomly selected subject. This score can range from zero if all subjects mention the same category ($P = 1$) to 6.75 ($P = 1/108$) if only one of all 108 subjects mentioned a given category. Category definitions were determined by an independent judge in a blind procedure. The C-score for a given subject is the sum of the scores to all the responses given by that subject. The C-total, each subject's total (unweighted) number of accepted (right) and non-accepted (wrong) responses, was recorded separately as a further criterion. Some subjects were discarded from the calculations because they obviously did not seriously participate in the tests and as a result their scores were either completely outside of the normal range or incomplete. In the first case the normal rule in SPSS for discarding outliers was applied. These cases are indicated in the results section.

For the rating of fit, normalized means were calculated. Normalization was performed by taking the rating of fit for each individual odor and dividing it by the mean of the 12 contextual ratings for that same odor by the same subject. Thus, values below 1.00 express a rating below the average, values above 1.00 a rating above the average rating for that odor.

If a subject explicitly remembered the odor from the testing room, his data were excluded from the analysis. For the rating of pleasantness the means per odor were calculated over subjects. For odor identification only an exact definition of an odor's name was counted as a correct answer. Since for some odors of a more general nature (ambient odor) no exact names could be given, only the results of the well-defined odors were taken into account in further treatment.

Results

Performance testing

Letter counting

The data were analyzed with two 3 × 3 ANOVAs (group C, J, L × interviewer A, B, C). Three cases were excluded from the analysis due to the extremely high rates of Error. There were no significant effects of group or interviewer on the measures of Amount or Error. For the measure of Error this result is basically caused by the rather similar results in groups C and J (C: mean = 0.27, SD = 0.14; J: mean = 0.27, SD = 0.15). Therefore, both these groups were combined for another 2 × 3 ANOVA (group C and J, L × interviewer A, B, C). There was a significant effect of odor condition [$F(1,99) = 4.59$, $P < 0.05$] on the rates of Error. Further analysis showed that Error rates in the lavender condition (group L) were lower than those in the combined conditions C and J (C and J: mean = 0.27, SD = 0.14; L: mean = 0.21, SD = 0.12).

Mathematical test

The influence of odor condition and interviewer on Error and Amount rates were analyzed with two 3 × 3 ANOVAs (group C, J, L × interviewer A, B, C). Ten cases were excluded from the analysis because of the extremely high rates of Error. There was a significant effect of odor condition [$F(2,89) = 5.99$, $P < 0.01$] on the Error rates but no effect on the rate of Amount. Here, the subjects made significantly more errors in the jasmine condition (group J) than in the two other conditions. (C: mean = 0.06, SD = 0.04; J: mean = 0.09, SD = 0.06; L: mean = 0.05, SD = 0.03).

Creativity test

Eight cases were excluded from the analysis of the C-scores due to no response in one of the four tasks; the application of the logarithmic scale was therefore not possible. A 3 × 3 ANOVA (group C, J, L × interviewer A, B, C) showed no significant effects of the factor group on the results of the C-scores [$F(2,91) = 2.069$, $P = 0.132$]. However a significant influence of the factor interviewer was found in the data [$F(2,91) = 8.618$, $P < 0.01$]. Further analysis showed that interviewer A produced the highest C-scores followed by interviewer C and B (A: mean = 20.57, SD = 6.55; B: mean = 14.49, SD = 4.88; C: mean = 17.688, SD = 5.93).

A 3 × 3 ANOVA (group C, J, L × interviewer A, B, C) on C-total showed a main effect of the two factors [$F(4,99) = 10.835$, $P < 0.01$], where both factors had a significant influence [interviewer: $F(2,99) = 14.523$, $P < 0.01$; group: $F(2,99) = 7.146$, $P < 0.01$]. There was no interaction between the factors [$F(4,99) = 0.954$, $P = 0.436$].

Like for the analysis of the C-scores, interviewer A caused the highest scores followed by interviewer C and B (A: mean = 59.19, SD = 13.72; B: mean = 43.06, SD = 12.53; C: mean = 49.81, SD = 14.13). The C-total was highest in the condition C followed by condition L and J (C: mean = 57.0, SD = 16.41; J: mean = 45.97, SD = 13.6; L: mean = 49.08, SD = 12.62).

Further analysis indicates an influence of the condition on the performance of the interviewers B and C, whereas interviewer A produced a relative stable result over the three different conditions. Table 3 shows the means and SDs for each interviewer over all conditions and the results of a one-way ANOVA which was computed for each interviewer over the conditions (interviewer i × condition C. J, L).

Rating of fit

The results of the rating of fit for all subjects together are

Table 3 Means and SDs of C-total for each interviewer over the conditions and the results of a one-way ANOVA

Interviewer	Group						ANOVA	
	C		J		L		F(df) value	P
	Mean	SD	Mean	SD	Mean	SD		
A	61.42	16.90	57.42	12.62	58.75	12.03	0.253(2,33)	0.778
B	50.67	16.31	35.67	8.86	42.83	5.69	5.380(2,33)	0.009
C	58.92	15.38	44.83	9.51	45.67	13.13	4.501(2,33)	0.019

shown in Table 4. Only one subject was excluded from the analysis because the person explicitly remembered smelling the odor (jasmine) in 'test room J'. This person was also omitted in the results of Table 5 below. All other subjects had been unaware of the presence of odors in the test rooms. Inspection of Table 4 shows that for these cases where a visual cue for the odor was present, the highest values are indeed found for this odor (coffee or leather), with the exception of the office with the cup of coffee. There, the rating of fit of the no odor control was equally high. It is also clear that, in cases where a visual odor cue was present, smaller relative differences between the mean and the median are found. This means that fewer subjects gave exceptionally high ratings than in the context without a visual cue. In general, it is remarkable that the means are in all cases higher than the medians. This cannot just be due to one or a few subjects, since the data are normalized per individual and therefore each individual average is 1.00 by definition. Furthermore, it is clear that in two contexts, the kitchen (with visual cue) and the train lavatory (without visual cue), odors were expected. They had the lowest values in the no odor column and both had high ratings of fit for most of the other odors, except for leather and laundry in the case of the kitchen and coffee and leather in the case of the lavatory, where the aftershave odor seemed to fit very well indeed. The three test rooms did not raise any special expectations with regard to odor. They had the highest fit values of all contexts in the no odor column (C = 1.24; J = 1.19; L = 1.34). The averages over all odors for them are not significantly different, although the one for room C (0.78) is somewhat lower than that of the other two (0.84 and 0.89), which are in the same range as those for the other contexts with the exception of kitchen and train lavatory.

Ratings of fit in the experimental groups and the control group

The results of the ratings of fit for the two test odors and the control odor to the three test rooms given by the three separate groups are shown in Table 5.

The influence of odor condition on the ratings of fit in the testing rooms was analyzed with a 3 × 3 ANOVA (group C, J, L × interviewer A, B, C) on the normalized magnitudes. For the visual context 'testroom C' (no odor) and the rating of fit of the control odor there was a significant effect of group [$F(2,99) = 3.92$, $P < 0.05$]; C rated the control higher than group J and L (C: mean = 1.5, SD = 0.84; J: mean = 1.15, SD = 0.57; L: mean = 1.1, SD = 0.68). A subsequent *t*-test showed no difference in the scores of group J and L. In the ratings of fit for 'testroom J' and the odor jasmine a significant influence of the factor group was also found, [$F(2,98) = 3.67$, $P < 0.05$]; here group J rated the odor of jasmine higher than group C and L did (C: mean = 0.55, SD = 0.46; J: mean = 0.98, SD = 0.45; L: mean = 0.64, SD = 0.82). A subsequent *t*-test showed no significant differences between group C and L. There was no significant influence on the ratings of fit for the context 'testroom L' and the odor lavender, although the ratings for lavender were highest for this context (C: mean = 0.81, SD = 0.59; J: mean = 0.65, SD = 0.55; L: mean = 0.88, SD = 0.86).

Ratings of pleasantness

At the end of the experiment, the pleasantness of the odors was assessed (see Table 1) and the subjects were asked to identify the odors. Lavender was judged to be more pleasant than jasmine. Exposure to the odors in the rooms had no influence on the pleasantness ratings. The three groups did not differ in their ratings of pleasantness. There were no gender differences in the pleasantness judgements. Pleasantness of the odor had also no effect on the rating of fit. Of the two odors for which a visual cue was provided, coffee was judged to be more pleasant than leather

Visual cues, identification of the odors and the rating of fit

As regards identification, the odor of jasmine was correctly identified and labeled by only one subject, as were most of the other odors with the exception of the odors of lavender (56.5% correct), coffee (77.8% correct) and leather (47.2% correct). Using a more lenient criterion by allowing, for instance, wood as a more general descriptor than sandalwood or cedarwood did not change the results in a significant way. No gender difference in correct identification was found for any of these. Exposure to lavender had no influence on the correctness of the identification of this odor. All groups identified lavender equally well. The correct or incorrect

Table 4 Normalized means and medians of ratings of fit between odors and contexts

Context content and visual cue	Mean of all odors	Rating of fit between odor and context, mean and median											
		Sandalwood	Ambient odor 2	Cedarwood	Laundry	Jasmine	Control	Lavender	Coffee	Ambient odor 3	After-shave	Leather	Ambient odor 1
Kitchen; cup of coffee													
Mean	1.4	1.3	1.6	1.5	0.9	1.6	0.7	1.5	2.9	1.5	1.1	0.5	1.8
Median		0.7	0.9	0.8	0.8	1.1	0.6	0.8	2.1	1.0	0.7	0.2	1.2
Train, large compartment; no													
Mean	1.0	0.9	0.9	1.0	1.1	1.1	1.0	1.0	1.1	0.9	0.8	1.1	1.1
Median		0.7	0.6	0.6	0.9	0.9	0.9	0.6	0.6	0.8	0.5	0.9	0.8
Car dashboard; leather interior													
Mean	1.0	1.4	1.0	0.7	1.1	0.9	0.9	1.4	0.5	1.0	1.0	1.6	1.0
Median		1.0	0.6	0.5	0.8	0.7	0.8	0.9	0.2	0.7	0.6	1.4	0.7
Testroom J; no													
Mean	0.9	0.8	0.9	0.9	1.0	0.8	1.2	0.8	0.5	1.0	1.0	0.7	1.0
Median		0.7	0.8	0.7	0.8	0.6	1.1	0.7	0.3	0.9	0.9	0.5	0.9
Office; cup of coffee													
Mean	0.9	1.0	0.9	0.9	0.9	0.8	1.1	0.9	1.2	1.1	0.9	0.7	0.9
Median		0.8	0.7	0.6	0.8	0.5	1.1	0.5	1.0	0.9	0.8	0.5	0.7
Train lavatory; no													
Mean	1.6	1.2	1.6	1.6	2.1	1.9	0.6	2.2	0.5	1.9	2.6	0.6	2.1
Median		0.8	0.9	1.3	1.8	1.3	0.4	1.3	0.1	1.7	2.0	0.2	1.8
Train, small compartment; cup of coffee													
Mean	1.0	1.0	1.1	0.8	0.9	0.9	0.8	0.8	1.6	0.9	0.8	1.2	0.8
Median		0.9	0.7	0.7	0.8	0.6	1.0	0.6	1.1	0.6	0.5	1.2	0.7
Testroom L; no													
Mean	0.8	0.7	0.7	0.9	0.8	0.7	1.3	0.8	0.6	1.0	0.9	0.7	0.9
Median		0.7	0.5	0.7	0.7	0.6	1.2	0.6	0.4	0.9	0.7	0.5	0.8
Men's department; leather jackets													
Mean	0.8	1.0	0.7	0.9	0.9	0.9	0.9	0.6	0.4	0.6	0.7	2.0	0.5
Median		0.9	0.5	0.6	0.7	0.6	0.9	0.3	0.1	0.4	0.5	1.8	0.4
Bank advisory room; no													
Mean	0.9	1.0	0.8	1.0	0.9	0.9	1.2	0.8	1.0	0.8	0.8	0.9	0.7
Median		0.9	0.6	0.9	0.9	0.6	1.1	0.6	0.6	0.6	0.7	0.9	0.5
Canteen room; leather jacket													
Mean	0.8	0.8	0.8	0.9	0.7	0.7	1.0	0.6	1.0	0.6	0.7	1.2	0.6
Median		0.7	0.6	0.6	0.7	0.5	1.1	0.4	0.8	0.4	0.5	1.2	0.4
Testroom C; no													
Mean	0.8	0.9	0.8	0.8	0.7	0.8	1.2	0.7	0.7	0.7	0.8	0.7	0.7
Median		0.7	0.6	0.5	0.6	0.6	1.1	0.5	0.4	0.5	0.5	0.6	0.6

Table 5 Rates of fit of the odors to the test rooms for each of the three groups

Fit of:	Group C (n = 36)	Group J (n = 35)	Group L (n = 36)	ANOVA	
				F(df) value	P
Odor C–testroom C	1.50^{a}	1.15^{b}	1.10^{b}	3.92(2,99)	<0.05
Odor J–testroom J	0.55^{c}	0.98^{d}	0.64^{c}	3.67(2,98)	<0.05
Odor L–testroom L	0.81	0.65	0.88	1.87(2,99)	0.337

Data in each row sharing the same superscript are not significantly different.

identification of lavender had no influence on the results of the performance tests in any of the three groups. The relationship between the correct identification of an odor name and the ratings of fit is shown in Table 6 for the odors coffee and leather, in the situations where a visual cue was present and in one special case where a visual cue was

Table 6 Means and SDs of the ratings of fit of the identifiers and non-identifiers of the odors coffee and leather in contexts with or without a visual cue

Visual context	Visual cue	Odor	Odor identification				*t*(df) value	*P*
			Correct		Incorrect			
			Mean	SD	Mean	SD		
Kitchen	cup of coffee	coffee	3.41	2.78	1.28	2.12	–4.04(48.02)	<0.01
Office	cup of coffee	coffee	1.26	0.97	0.68	0.64	–3.46(56.44)	<0.01
Train compartment	cup of coffee	coffee	1.67	1.79	1.37	1.27	–0.76(106)	0.45
Car dashboard	leather interior	leather	2.02	1.65	1.15	1.01	–3.34(106)	<0.01
Men's department	leather jackets	leather	2.35	1.55	1.62	1.52	–2.47(106)	<0.05
Canteen room	leather jacket	leather	1.33	0.83	1.10	1.18	–1.15(106)	0.25
Train lavatory	no	leather	0.26	0.40	0.99	1.53	3.50(64.29)	<0.01

absent. In all other situations without a visual cue there was no difference in the ratings of fit between correct and incorrect identifiers.

Whenever an odor-related visual cue was present in the picture, the rating of fit of the corresponding odor to the picture was the highest one found for that picture (see Table 4). As could be expected, there was a clear relationship between the ability to identify the odor and the rating of fit in most cases where a visual cue was present (see Table 6). In two of the six cases (train compartment and canteen room) the identifiers rated the fit not significantly higher than the non-identifiers. In the contexts without a visual cue no differences between identifiers and non-identifiers were found for the odors of either coffee or leather, with the exception of the context train lavatory. Here the non-identifiers for leather rated the fit of this odor significantly higher than the identifiers.

Odor exposure, identification of the odors and the rating of fit

In the condition lavender the correct identification of the odor name influenced the ratings of fit. Table 7 shows the means and Sds of the ratings of fit between test room L and lavender for correct and incorrect odor identifiers in the groups that were not exposed to lavender (C + J) and the group that was (L).

A 2 × 2 ANOVA (group C + J, L × identification correct, incorrect) shows no main effects, but a significant interaction [group × identification $F(1,104) = 4.66$, $P < 0.05$] is found. Further testing with one-way ANOVA showed a significant difference between the two groups for the ratings of fit of the incorrect identifiers. The incorrect identifiers in the lavender group rated the fit higher than the incorrect identifiers in the other groups. No such difference was found for the correct identifiers. These findings explain the fact that for the total group no significant proof of implicit memory was found for lavender in Table 4. The subjects who

Table 7 Means and SDs of the ratings of fit between testroom L and the odor of lavender for the subjects who correctly or incorrectly identified lavender in group L and in the other groups (C + J)

Identification of lavender	Group		ANOVA	
	C + J	L	*F*(df) value	*P*
Incorrect				
Mean	0.61	1.1	4.64(1,45)	<0.05
SD	0.54	1.0		
Correct				
Mean	0.82	0.71	0.44(1,59)	0.51
SD	0.58	0.71		

can identify this odor do not show such an implicit memory at all and therefore their results are responsible for the lack of significance found for the total group.

Discussion

The first conclusion of this study is that unconscious perception of an odor can significantly affect the rate of errors made in the mathematical and letter counting tests. In the presence of the odor of lavender subjects made less errors than in the presence of no odor or the odor of jasmine. At first sight these results are contrary to the supposition of Torii *et al.* (1988), who, on the basis of physiological measurements, supposed that jasmine had a stimulating and lavender a sedative effect. However, if one supposes that performing in psychological tests is a rather stressful experience, the results may be explained by the Yerkes–Dodson law, which states that when the arousal level has passed a maximum, the performance will decrease. If lavender is indeed a sedative stimulus and helps to reduce the stressful arousal of the subject, it would lead to a better performance, whereas further arousal by jasmine would have the opposite effect. Whether the same result would have been obtained under normal unstressed conditions is doubtful. This means that one cannot base predictions about the effects of odors on physiological measures such as variations in the CNV (Torii *et al.*, 1988) only. The odors also had an influence on the number of valid responses in the creativity test, but not on the quality of these alternatives. Again the subjects did less well in the jasmine condition than in the control condition, but this time the difference between the jasmine and the lavender conditions was minimal. Furthermore, it could be seen that the odor conditions influenced the numbers of responses written down by two of the interviewers. Whether this was due to the utterances of the subject or to the behavior of the interviewers cannot be decided on the basis of these results.

Secondly, the present experiment confirms the finding by Degel and Köster (1998) that whenever people detect visually a possible odor source that might be related to the odors they smell, they will make the connection (Table 6). It is quite understandable that they do so, especially when they identify the odor that belongs to the source. In a way this may also explain the exceptional case of the odor of leather in the train lavatory, where the incorrect identifiers rated the fit between odor and environment much higher than the correct identifiers. If the odor of leather is identified it does not bear a special relationship with a toilet, but if it is not recognized as such it may be related, because it has many animal and fecal undertones.

The third and perhaps most important conclusion of the study is that implicit memory for odors truly exists. Not only is it clear that odors are expected more in some situations (kitchen and train lavatory) than in others (Table 4), but when a subject is exposed unknowingly to an odor, he/she later connects this odor with the place he/she has been exposed to it. This is true even when that person remains completely unaware of the fact that there ever was an odor in the room in which he/she was tested. The most surprising result of this study is that this implicit memory seems to work only in subjects that do not know the odor well enough to identify it by its proper name afterwards. This was obviously the case in the control condition where no odor was present, in the jasmine condition where none of the subjects (except one who remembered having smelled it in the test room and was discarded from the analysis) could identify the odor, and for the non-identifiers in the lavender condition. On the other hand, the people who knew the name of lavender and identified it afterwards behaved like the subjects in the two other groups. It should be stressed once more that none of these subjects remembered the presence of lavender in the test room. When asked where and when they had smelled this odor for the last time before the last session, none of them mentioned the room or even the laboratory. Four possible explanations of this phenomenon are suggested. Two of these are based on the supposition that the subjects did consciously perceive and recognize the odor, but subsequently forgot that they had smelled it in the room. In the first place, this could simply be due to the fact that they thought the recognized odor to be completely irrelevant with regard to the test situation in which they were brought. In the second place it could be due to the retroactive inhibition caused by the odors in the rating of fit procedure that preceded the identification question. In that case the identifiers had identified lavender in the test room and had stored it in their memory, but had forgotten it under the influence of the many odors (including lavender) that they were exposed to in the rating of fit task. If true, this explanation would invalidate the supposition of Engen (1991) and Herz and Eich (1995) that the longevity of olfactory memory is due to the absence of retroactive inhibition. The third and fourth possibilities would be that the presence of the name lavender in verbal memory blocks the build-up of or the retrieval from the implicit memory. In the last case, it is supposed that the subjects did not identify the odor in the test room and kept only an implicit memory of it, just like the non-identifiers. When in the rating of fit session they were confronted explicitly with the well-known odor of lavender, they simply denied the existence of this subtle memory, because they felt that if the odor had been there they would certainly have noted it. This might also explain why their average rate of fit was even somewhat (although not significantly) lower than that of the correct identifiers of lavender in the other groups. The other possibility might be that knowing an odor by name makes it impossible to build up new episodic memories for that odor, even when one is not aware of its presence. This explanation is in line with the supposition of Engen (1991) and Herz and Eich (1995) to a certain extent. It might mean that once an odor has entered in semantic memory, this memory takes over and prevents further interference by retroactive inhibition in episodic memory. The identifiers do not store the new episodic odor experience. This would also explain why proactive interference is so strong in olfactory memory (Lawless and Engen, 1977; Engen, 1991). Nevertheless, new episodic odor experiences are being built up by the non-identifiers when no interference by semantic knowledge is involved. Whether such new links do not cause retroactive inhibition in episodic memory remains to be seen. The non-identifiers differ from the identifiers mainly through the fact that they cannot find the connection between odor and name in semantic memory, because it is hardly imaginable that they have never encountered lavender (or jasmine) in their life and heard the names of these odors.

The fact that the train lavatory was the only case in which the non-identifiers of leather rated the fit of this odor significantly higher than the identifiers fits well into this last hypothesis, although the explanation offered above may apply equally well. Furthermore, if the toilet served as a visual cue, it could do so only for those who did not recognize the odor.

Whatever the truth of these hypotheses, which are now the subject of further research, the accidental finding that the non-identifiers have a better implicit memory seems to be in opposition with the general finding that knowing the correct name of an odor has a positive effect in odor recognition experiments (Lyman and McDaniel, 1986, 1990). The question then arises of what the differences between the two methodological approaches to odor memory are that lead to such contrasting results. First of all it should be noted that in odor recognition experiments the subject is asked explicitly to indicate whether he/she has smelled the odor on a previous occasion, whereas in the research presented here the presence of the odor in the learning phase was never made explicit. Furthermore, in the learning phase of recognition experiments the odors are explicitly presented to the subjects, even if they are unaware of the fact that they will later be asked to recognize them. If in these situations the subjects label the odors with a name and thus enter them into semantic memory, they have two ways of remembering them and it is not surprising that they do so better than when they do not find a name for them. That finding the right name leads to an even greater advantage is also logical. This perhaps tells more about semantic memory than about odor memory.

Acknowledgement

This study was granted in part by the German Savings Bank Association (Deutscher Sparkassen- und Giroverband), Bonn.

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Accepted February 9, 1999