Chem. Percept. (2009) 2:59–69
DOI 10.1007/s12078-009-9045-5

# Odors Cue Memory for Odor-Associated Words

**Lorenzo D. Stafford · Sarah Salehi · Bridget M. Waller**

Received: 27 November 2008 / Accepted: 31 March 2009 / Published online: 16 April 2009


**Abstract** The ability of odors to cue vivid and emotionally intense memories is well-known. However, the majority of research has focused on the extent to which odors can act as environmental cues to memory, where odors are presented alongside the stimuli to be remembered, rather than the extent to which pre-existing associations between odor and odor-related stimuli might influence memory. In this study, participants ($n$=45 females in each experiment) were presented with words (two groups of odor-associated words and one neutral) on a computer screen and randomly assigned to one of three conditions where they recalled the words while inhaling from a bottle either rosemary, jasmine, or no odor (experiment 1) and peppermint, bergamot, or no odor (experiment 2). In experiment 2, participants then completed a lexical decision task (LDT). Experiment 1 revealed that, for those in the rosemary group, significantly more rosemary versus jasmine and neutral words were recalled. Experiment 2 replicated this effect for peppermint, though no odor-congruent effects were found in the LDT. These findings demonstrate that certain odors are able to cue memory for odor-associated words. Results are discussed in relation to connected odor association research and possible theoretical frameworks to account for these findings.

**Keywords** Olfaction · Memory · Lexical Decision Task · Odor Imagery · Emotion

L. D. Stafford (✉) · S. Salehi · B. M. Waller
Department of Psychology, University of Portsmouth,
King Henry Building, King Henry I Street,
Portsmouth PO1 2DY, UK
e-mail: lorenzo.Stafford@port.ac.uk

## Introduction

Olfaction is unique among the sensory modalities in its relationship to memory. Physiologically, olfaction is the closest to both the amygdala and hippocampus (Herz and Engen 1996), which may well explain the ability of odors to induce intense emotional memories (Chu and Downes 2000; Herz 1997). The aim of this research is to explore the pre-existing associations we have to odors and their ability to influence behavior. For instance, most of us are familiar with anecdotal evidence that the smell of freshly brewed coffee from a café increases our desire for coffee and possibly related products. Hence, it is the (presumably) learned association that the odor of coffee signals not simply coffee itself but additionally memories associated to that odor that is the focus of the current investigation. The experimental evidence for odors specifically cueing odor-associated behavior is still lacking. One study, for example, examined whether odors found to have a greater connection to certain activities (i.e., odor of grass to gardening activity) were capable of influencing the sales of odor (thematically) congruent versus incongruent magazine titles (Schifferstein and Blok 2002). No significant differences were found between the odor conditions; however, as the study used only the sales of the magazine titles as the main measure, it may be that any changes in attention were not necessarily associated with purchasing behavior. A second study (Morrin and Ratneshwar 2003) investigated whether recognition for brands of products was facilitated when both encoding and retrieval took place in the same scented environment with an odor-associated to those brands (i.e., geranium odor to deodorant, skin lotions, and laundry detergents). Results in both recall and recognition failed to show the expected effect, although overall memory recall was enhanced when the encoding environment was scented compared to a no-odor condition.

In the more theoretical cognitive domain, research has examined to what extent odors can act as environmental cues to memory, also known as "context-dependent memory" (CDM). Experiments have shown that memory performance for words is increased when the odor diffused into the test environment was the same at learning and recall (Schab 1990). In the key experiment, from the 40 words to be recalled, seven were related to the diffused odor (apple and cinnamon), including for example "pie" and "cider." Participants were assigned to one of three groups: (1) same odor at learning and test and also asked to think about and imagine the smell of that odor; (2) just given the instructions only; (3) no odor present or instructions. Results revealed that overall memory was highest for those exposed to the odor with the instructions. More interestingly, memory for the odor-related words was greater in the first two groups compared to those experiencing neither odor nor imagery instructions. However, there was no difference between the first two groups, suggesting that there was no additional benefit for cueing odor-associated words with the relevant odor compared to only imagining the odor. Recent work has shown that the same odor at learning and recall without imagery instructions can nevertheless yield enhanced (delayed) recall for words associated to that odor compared to a no-odor control (Parker et al. 2000). This implies that, although semantic cues generated by imagery alone compared to odor plus imagery are just as effective at cueing odor-associated words, the experience of inhaling an odor by itself (without imagery) still confers an advantage to no odor in recall. One limitation of both CDM studies (Parker et al. 2000; Schab 1990) is that only one odor was used in each study and it is, therefore, uncertain if the unique relation between the odor and the associated words was responsible for the enhanced memory or whether the same effect might occur with an alternative odor.

The majority of research to date has focused on the extent to which odors can act as environmental cues to memory, where odors are presented with the stimuli to be remembered, rather than the extent to which pre-existing associations between odor and odor-related stimuli might influence memory. This latter function is particularly important if we are to understand the ability of odors to prime/cue behavior. The present research, therefore, aimed to examine this using a direct method of odor inhalation whereby the odor would be inhaled explicitly by the individual, rather than using an odor diffuser to release the odor into the testing environment. Using this method ensures unambiguous attention to the odor and also permits greater control on the delivery of the odor (Ilmberger et al. 2001; Sugawara et al. 1999). Additionally, previous studies have not ascertained the associations specific individuals hold with the delivered odors (Schifferstein and Blok 2002) or response questionnaires were closed to a number of options thought to be important by the investigators (Morrin and Ratneshwar 2003; Schifferstein and Blok 2002). We completed a prestudy in order to select two odors with the highest degree of agreement in individual associations to that odor and produce a list of most frequently associated words for each of the two odors. Additionally, the prestudy aimed to provide data on the sensory perception of the tested odors in order that the two selected odors could be compared on the various dimensions. This was achieved using visual analog scales (VAS) as used in previous research (Ilmberger et al. 2001; Stafford and Yeomans 2005). In the first experiment, individuals completed a free recall task using the words selected from the prestudy while inhaling one of the odors, where it was predicted that recall would be enhanced when odor and odor-associated words were congruent.

## Prestudy

### Participants

The 14 participants were all female university students [as females describe more emotional and clearer memories than males (Herz and Cupchik 1992; Laird 1935) and have superior olfactory sensitivity (Doty et al. 1981)] aged between 18 and 24 years (mean, 20.4; SD, 1.5 years) and all had English as their first language. University of Portsmouth ethics procedures were followed throughout the study.

### Design

The study used a within-subjects design where participants sampled ten odors in a randomized order.

### Odors

The ten odors used in this experiment were selected on the basis of providing a wide selection of contrasting essential oils and were all from Holland & Barrett (Portsmouth, UK): bergamot (*Citrus bergamia*), cedarwood (*Juniperus virginiana*), jasmine (*Jasminum grandiflorum*), lavender (*Lavandula officinalis*), marjoram (*Origanum majorana*), neroli (*Citrus aurantium*), patchouli (*Pogostemon cablin*), peppermint (*Mentha piperita*), rosemary (*Rosmarinus officinalis*), and ylang-ylang (*Cananga odorata*). Odors were prepared by placing a single cotton wool pad (Boots, Portsmouth, UK) inside a glass bottle (2.5 cm diameter at the opening and 13 cm high) and injecting 200 μL of the respective odor onto the pad and sealing the bottle with a plastic lid.

Procedure

On arrival, participants were asked if they had a cold and those who did were rescheduled for another day. They were then presented with the ten odors in a randomized order for each participant and instructed to smell each odor in the order presented (numbers were placed in front of each bottle for clarification). For each odor, they were asked to remove the cap and inhale normally through the nose, exhale through the mouth and complete the questionnaire. The questionnaire assessed each odor using five questions. Participants rated how alerting (1) and relaxing (2) the odor made them feel or they associated with the odor and how intense (3) and pleasant (4) was the odor. Participants made their responses on a 100-mm VAS anchored at "not at all" and "extremely." The final question asked "What immediate words/emotions/memories do you associate with this odor?" (minimum of three). Once they had completed this, they were instructed to fix the cap to the bottle, take a few breaths of fresh air before proceeding to the next odor, and repeat as before. When all odors had been sampled, they were given a full debriefing.

Results

*Odor-Associated Words*

Since the main purpose was to gather a list of words most highly associated to each odor, it was decided, for each odor, to note all the words listed by at least two of the participants (this being the lowest level of common agreement). Each of the odors was then compared to see which ones yielded the most frequently associated words. This process was completed by two judges with a high level of agreement (above 80%). This analysis resulted in six odors (rosemary, jasmine, peppermint, lavender, bergamot, and patchouli) that each yielded seven words mentioned by at least two participants. Patchouli was excluded since two of the words (chewing gum and mint) were likely an effect of odor order (e.g., peppermint presented before). Four odors were selected for the experiments on the basis of the highest frequency of associations and distinctiveness from each other. The most commonly associated words/themes for each of the ten odors are shown in Table 1.

*Ratings*

Repeated-measures analysis of variance (ANOVA) of the VAS revealed a significant effect of odor on intensity, $F(9, 117)=5.91$, $p<0.0001$, where pairwise comparisons revealed jasmine to be the least and ylang-ylang as the most intense odors (Table 2). There was also a significant effect of odor on ratings of pleasantness, $F(9, 117)=4.04$, $p<0.0001$, with mean comparisons demonstrating patchouli to be the least and peppermint the most pleasant odors (Table 2). Ratings of alertness revealed a significant effect of odor, $F(9, 117)=7.18$, $p<0.0001$, where jasmine was the least and ylang-ylang the most alerting odors (Table 2). Finally, in terms of relaxing ratings, a significant effect of odor was found, $F(9, 117)=4.16$, $p<0.0001$, with mean comparisons revealing patchouli to be the least and jasmine as the most relaxing odors (Table 2).

## Experiment 1

The prestudy found that, when presented with several different odors, the spontaneous associations female individuals made were quite varied, though some odors yielded distinctly higher rates of agreement. In particular, participant's responses to the odors of rosemary, jasmine, peppermint, lavender, and bergamot clearly contained a high number of concordant words compared to the remaining odors. In terms of rosemary, the major theme related to products associated to cold remedies, e.g., "vapor rub", "menthol." In contrast, for jasmine, the theme was mainly connected to "flowers", "gentle." These findings suggest that, although responses to odors can be very personal and unique (e.g., "reminds me of grandmother's house"), there is also some overlap of the same responses. In previous work, researchers have simply constructed a list of items thought to be associated to an odor and asked individuals how strongly they thought the odors were associated to such words (e.g., Schifferstein and Blok 2002). Such approaches have the advantage of permitting inferential analysis of the data to determine significant differences; however, they have less ecological validity in that items are initially proposed by the researchers themselves. The results of this prestudy are also in general support of earlier work on the durability and emotional intensity of inhaled odors (Aggleton and Waskett 1999; Herz 2004; Herz and Cupchik 1992).

Experiment 1, therefore, aimed to see whether odors were capable of influencing memory to stimuli (words) associated to that odor. On the basis of the highest frequency of associations and distinctiveness from each other, rosemary and jasmine were selected for the test odors in experiment 1. It was, therefore, hypothesized that recall would be enhanced when odor and odor-associated words were congruent.

Participants

Forty-five Portsmouth university students were recruited for the study. Participants were all females aged between 18 and 24 years (mean, 19; SD, 1.2 years) and all had English as their first language. The participants did not differ

**Table 1** Most commonly associated words/themes for the ten odors (prestudy)

| | Word/theme | Frequency | Example of personal memory |
|---|---|---|---|
| Bergamot | Lemony/citrus/zesty | 5 | Drinking Coca-Cola |
| Cedarwood | Wood/chopping logs/building work | 6 | Church at Easter |
| Jasmine | Flowers | 3 | Nana's house |
| Lavender | Lavender | 4 | Long baths |
| Marjoram | Coughs/colds | 6 | Bedroom when younger |
| Neroli | Plants/crushed plants | 3 | Quietus mind |
| Patchouli | Herbs/forest/green/fairgrounds | 5 | Being sick |
| Peppermint | Mint | 8 | Christmas |
| Rosemary | Vapor rub | 6 | Being cared for |
| Ylang-ylang | Disinfectant/chemicals | 5 | Hospitals |

significantly in age between the three groups: control (18.8 ±0.3), jasmine (19.1±0.3), and rosemary (19.0±0.4). The study was approved by the University of Portsmouth ethics committee (BPS guidelines).

## Design

Participants were randomly allocated to one of three groups: jasmine, rosemary, and no odor and all participants completed a memory task containing three types of words. The experiment, therefore, used a mixed design with group as between-subjects variable and word type as within-subjects variable.

## Word Stimuli

Based on the findings of the prestudy, seven odor-associated words were selected for each of the test odors (jasmine and rosemary) together with seven neutral words relating to motor vehicles/driving and were matched as closely as possible for word length, number of syllables, written word frequency, and imageability (Francis et al. 1982). The choice of motor vehicles/driving was random but the rationale for using such a neutral word group was to match any possible categorical priming effect that could arise for words in the jasmine and rosemary groups. The use of such categorical controls have been used in a number of previous studies (e.g., in a modified Stroop, Green & McKenna 1993). In total, there were 21 words (Table 3).

**Table 2** Mean (SEM) prestudy ratings for intensity, pleasantness, alerting, and relaxing

| | Intensity | Pleasantness | Alerting | Relaxing |
|---|---|---|---|---|
| Bergamot | 60.2±6.5 | 53.0±7.3 | 51.4±6.0 | 42.1±7.8 |
| Cedarwood | 53.2±6.4 | 27.4±6.0 | 41.4±4.5 | 31.0±6.0 |
| Jasmine | 33.4±5.3 | 50.3±6.6 | 33.9±5.6 | 60.5±5.5 |
| Lavender | 61.1±5.2 | 36.0±9.8 | 50.6±5.3 | 38.3±8.5 |
| Marjoram | 65.7±5.5 | 42.8±5.5 | 58.9±3.7 | 44.8±6.7 |
| Neroli | 37.4±4.5 | 44.1±6.2 | 35.9±5.3 | 47.5±6.2 |
| Patchouli | 52.8±6.9 | 20.9±5.8 | 39.1±5.3 | 23.0±4.5 |
| Peppermint | 60.9±5.5 | 63.7±5.5 | 58.5±5.5 | 43.3±7.5 |
| Rosemary | 63.0±7.4 | 41.2±5.3 | 63.4±5.7 | 38.1±6.3 |
| Ylang-ylang | 72.6±5.2 | 32.5±5.7 | 67.6±3.2 | 25.0±6.1 |

## Free Recall Memory Task

Participants were advised to focus on a fixation symbol (+) on the screen, followed by a briefly displayed series of words, and their task was to try and remember each word. Words were presented in lower case courier font (size 18) displayed in the center of the screen. Each word remained on the screen for 3 s before being replaced by the fixation symbol and the successive trial. To minimize any categorical effects in word presentation, the words were randomized but whereby no two words of the same group could appear in succession. The memory task used here was written using E-Prime (version 1.1 SP3) and was conducted on a Gateway 2000 PC (531 MHz) running Windows XP Professional (version 2002).

## Odors and Administration

Two odors were selected from the prestudy: jasmine and rosemary and, due to the differences in intensity, a pilot was conducted in order to calibrate the two essential oils. Six females (who took no further part in the experiment) were

**Table 3** Word stimuli used in the memory task (experiment 1)

| Neutral | Jasmine | Rosemary |
|---|---|---|
| Wheel | Flower | Clear |
| Drive | Gentle | Colds |
| Garage | Grassy | Fresh |
| Brake | Herbs | Menthol |
| Journey | Pollen | Nose |
| Wiper | Spring | Olbas |
| Traffic | Summer | Vaporrub |

asked to rate the two odors on intensity (using VAS) in a counterbalanced order. This revealed mean intensity ratings for rosemary (59.3; SD, 10.5) that were higher than jasmine (45.8; SD, 21.2). On the basis of these results, the volume of the two odors for the main study was adjusted whereby 200 µL of rosemary and 400 µL of jasmine were used. Apart from this difference, preparation was the same as for the prestudy.

## Procedure

Participants were told prior to the start that the experiment would consist of a computer task and smelling a pleasant odor (if in relevant condition) and completing a questionnaire. On arrival at the laboratory, participants completed an informed consent form and then undertook the computer task. When this was completed, they were then asked to count backwards in threes from 500 for 3 min as a distracter task. Following this, those in the two odor conditions were presented with a bottle containing the relevant odor and instructed to remove the cap and inhale normally through the nose, exhale through the mouth and write down one word from the previously presented list in any order. They were then asked to take a breath of fresh air and to repeat the process continuously, trying to remember a different word each time, and if they could not recall a word on a particular trial to simply keep repeating the process. Participants in the no-odor condition were instructed to write down as many words as they could remember in any order. When 3 min had elapsed, participants were thanked for their time and given a full debriefing. Participants were offered either course credits or monetary compensation for taking part in the study.

## Data Analysis

The number of words recalled correctly for each participant was subjected to a repeated-measures ANOVA using the within-subjects factor of word (jasmine, rosemary, and neutral) and the between-subjects factor of group (jasmine, rosemary, and no odor).

## Results

### *Free Memory Recall Task*

Analysis revealed a significant main effect of word, $F(2, 84)=4.37$, $p<0.05$, with mean comparisons revealing significantly higher recall for both jasmine-associated (3.6± 0.2) and rosemary-associated (3.8±0.2) words compared to the control (3.1±0.2, both $p<0.05$), which, however, did not differ from each other. There was also a main effect of group, $F(2, 42)=6.12$, $p<0.01$, with post hoc comparisons demonstrating significantly lower recall for both jasmine (3.3±0.2) and rosemary groups (3.1±0.2) compared to the control (4.2±0.2, both $p<0.01$), again though not differing from each other. Importantly, the word×group interaction was significant, $F(4, 84)=2.53$, $p<0.05$, with mean comparisons revealing that, consistent with the prediction, more words were recalled when group and word were congruent (Fig. 1). Post hoc comparisons further demonstrated that, when each group was analyzed separately, there were no significant differences in words recalled in the control group. In the case of the jasmine group, significantly more jasmine-associated words compared to neutral words were recalled ($p<0.05$), but no differences were found between jasmine- and rosemary-associated words ($p>0.1$). For the rosemary group, however, significantly more rosemary-associated words were recalled compared to both neutral and jasmine words (both $p<0.05$).

## Discussion

The study found that, consistent with the prediction, participants recalled more odor-associated words relative to the non-odor associated and neutral words when inhaling the corresponding odor. Hence, those in the jasmine and rosemary groups recalled significantly more jasmine- and rosemary-associated words compared to neutral words, with no differences for those in the no-odor condition. However, the effect was most apparent in the rosemary odor group where recall was significantly higher for rosemary-associated words compared to both jasmine-associated and neutral words. These findings demonstrate that memory for words related to a specific odor can be enhanced when smelling the congruent odor simultaneously and are consistent with related work in CDM (Parker et al. 2000; Schab 1990), which found that memory was enhanced when the same odor was present at encoding and recall. The work here extends that research to show that odors can cue odor-associated words even when

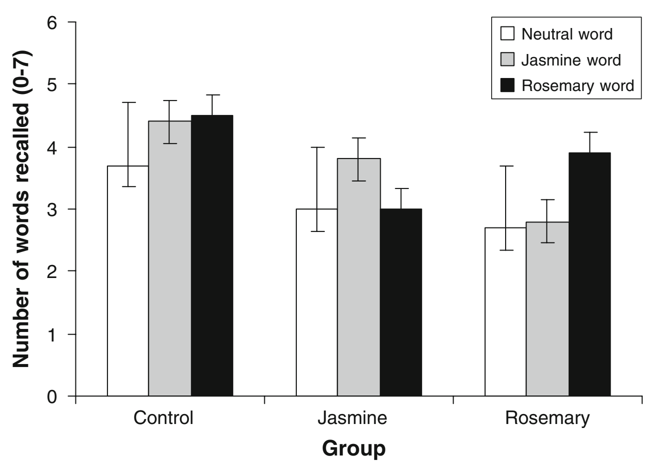


**Fig. 1** Mean (±SEM) number of words recalled depending on word type and odor condition in experiment 1

presented at recall only and hence are not simply an environmental cue as in CDM. Furthermore, it was unclear from the previous work whether the effects observed were due to the specific odor used or whether the same effects could be produced with another unrelated odor. It appears from the results here that this may depend on the odor used, since those in the rosemary group recalled significantly more rosemary- versus jasmine-related words, but no differences were found for those in the jasmine group. This could be due to the odor of rosemary being more familiar to participants compared to jasmine and thus producing a stronger connection to the related words and thereby influencing recall. It may also be due to differences in odor intensity, where although an attempt was made to match the two odors on this dimension, it could be that due to inherent differences, stronger odors such as rosemary provide a better memory cue. The main criteria for selecting the two odors here were based on distinctiveness between the two odors and strength of memory association. However, since odor intensity may not have been completely matched, together with differences in pleasantness, it could be that these are important features in yielding the odor-congruent memory effect and is something that experiment 2 wished to address.

In addition, one could argue that the memory paradigm used in experiment 1 was not consistent with priming research in that participants were specifically asked to memorize the words. Using a more implicit or incidental learning approach would also mean that the influence of the odor may be greater since individuals would not be actively involved in word rehearsal. It was, therefore, decided to use an incidental learning approach, similar to that used in previous related work (Schab 1990). Another issue with experiment 1 was that memory, overall, was poorer in the two odor groups compared to no odor, suggesting that inhaling from a bottle (perhaps unsurprisingly) acted to interfere with the memory task and impair performance. Though it is important to note that this overall impairing effect of smelling an odor was evidently not impacting on the specificity of the effects observed, hence, those inhaling rosemary were uniquely better at recalling rosemary relative to jasmine and neutral words. Nevertheless, in order to use a more appropriate control, participants in this condition in the follow-up experiment would inhale from a blank bottle.

## Experiment 2

A second experiment was completed to address the methodological limitations of experiment 1 and additionally to examine whether effects would also be evident using an attentional task (lexical decision task [LDT]). The aim was to ascertain whether individuals who had recently been exposed to an odor would be faster at recognizing words associated to that odor. Related research has shown that direct inhaling of pleasant and unpleasant odors can influence reaction times in an affective priming study (Hermans et al. 1998). More recently, it has been reported that a citrus cleaning odor diffused in the test environment led to faster responses to cleaning-related compared to control words in a LDT (Holland et al. 2005). Therefore, in this context, the LDT is a measure of the salience of words according to odor exposure, where it is assumed that faster responses to odor-congruent cleaning words versus neutral words are taken to suggest that attentional processes have been influenced by that odor.

In both of the above studies, however, the odor was present while participants completed the task and it is, therefore, uncertain whether recent exposure to an odor can influence attention. Nevertheless, since earlier work found an effect of merely imagining an odor on memory recall (Schab 1990), there are grounds for theorizing this may be the case. To explore this question, participants in experiment 2 were exposed to the relevant odor as part of the memory task per experiment 1 and then completed a LDT where, instead of having to smell the relevant odor, they would be asked to imagine the smell of the previously presented odor to test whether this would influence lexical decisions to odor-relevant words.

It was predicted that free recall would be highest when odor condition and odor-associated words were congruent. Furthermore, the effect of odor pre-exposure was explored on attention where it was theorized that responses would be fastest for those participants where odor and odor-associated words were congruent.

### Participants

Forty-five female Portsmouth University students were recruited for the study. Participants were aged between 18 and 24 years (mean, 18.82; SD, 1.3 years) and all had English as their first language (Table 4). The study was approved by the University of Portsmouth ethics committee (BPS guidelines).

### Design

The study used a mixed design where participants were randomly allocated to one of three groups (bergamot,

**Table 4** Mean (SEM) group characteristics experiment 2

| Group | Age |
|---|---|
| No odor | 18.3±0.2 |
| Bergamot | 19.2±0.4 |
| Peppermint | 18.9±0.4 |

peppermint, and no odor) and all completed a memory task and a LDT containing three and four different types of words, respectively. Consequently, group was the between-subjects factor, whereas word type was the within-subjects factor.

### Odor Familiarity

In order to measure odor familiarity, participants were asked two questions: “How familiar was the odor you smelled to you?” and “What do you think was the odor you smelled?” Participants made their odor familiarity rating on a 100-mm VAS anchored at “not at all” and “extremely” and used an open response format to provide an answer to the second question.

### Odors and Administration

The two odors selected for the present study were bergamot (*C. bergamia*) and peppermint (*M. piperita*), as they were shown in the prestudy to be similar in intensity, pleasantness, alerting, and relaxing power [no significant difference on all measures, $ps>0.1$]. The odors were administered by injecting 200 μL of the respective essential oil on a cotton wool pad, placing this pad into a glass bottle, and closing the bottle with a plastic lid.

### Word Stimuli

In order to ensure that the odor words used could not be mistaken for a different odor and also to obtain the most frequently associated words, a pilot study was conducted where ten females were given a word list containing 30 words and were asked to rate on a VAS how much they associate each of the 30 words with one of the two test odors they were inhaling continuously. After a short break, the same 30 words had to be rated while smelling the other odor. Participants also stated how familiar the two odors were to them using a 100-mm VAS. The 30 words were taken from the prestudy. Based on the results of the pilot here, the seven most highly associated words were used in the memory task: bergamot (citrus, zesty, clean, fresh, comfort, baths, and cough) and peppermint (mints, menthol, gum, toothpaste, spearmint, mouthwash, and vapor rub) together with seven neutral (wheels, driver, garage, brake, journey, wiper, and traffic) words belonging to the category driving. There were no differences in familiarity between bergamot (63.2±5.3) and peppermint (63.0±10.9), $t(9)=0.16$, $p>0.9$. For the LDT, rather than use the same set of words for the memory task which would have obviously affected performance in the LDT (and not the aim here), the next most highly associated words, seven for each category, were selected from the pilot: bergamot (chemicals, disinfectant, relaxation, nostalgic, home, massage, and drowsy), peppermint (sweets, unpleasantness, dentist, winter, laboratory, dizziness, and old), neutral (sharpener, marker, paper, rubber, sellotape, glue, and pencil) together with 21 nonwords (e.g., pramdin). The word groups were matched as closely as possible for word length, number of syllables, written word frequency, and imageability (Francis et al. 1982).

### Free Recall Memory Task

This task was identical to experiment 1. However, since we were interested in using an incidental learning approach, here, participants were instructed that words would be briefly displayed on the screen. Furthermore, for each word presented, they had to decide whether it was pleasant or unpleasant by pressing the “Y” or “N” key, respectively. So, although there was no specific instruction to memorize the words, the act of making a decision would require at least some form of deeper processing and is similar to previous work (e.g., Schab 1990).

### Lexical Decision Task

Participants were instructed to focus on a fixation symbol (+), which appeared in the middle of the screen for 1,000 ms before being replaced by a word or a pseudoword. Participants were advised to decide as quickly and as accurately as possible whether the presented word was a real or pseudoword by pressing the “Y” labeled key when it was a real word and the “N” labeled key when the word was a pseudoword. The words were presented in random order, courier new font size 20, and remained on the screen until the participants responded. Importantly, participants were furthermore instructed to imagine the odor they had smelled in the previous task. This was done by presenting the reminder “Imagine that smell from the bottle” before each single trial for 1,500 ms in the middle of the screen. As in the memory task, to minimize any categorical effects in word presentation, the words were randomized but whereby no two words of the same group could appear in succession.

### Procedure

On arrival, participants were seated in front of a computer screen and read the instructions for the memory task and instructed to start when they were ready. Once this task had finished, they were instructed to count backwards in fives from 500 for 30 s as a distraction. Participants were then given a glass bottle, which contained either a wool pad with bergamot, peppermint, or a plain wool pad with no odor, depending on the participant’s group. The instructions were then identical to experiment 1. When 5 min had elapsed, the free recall task was finished and participants completed the LDT. Participants then filled in an odor familiarity rating questionnaire. In order to minimize any lingering odors that remained, two identical cubicles [the dimensions of these testing rooms were 3.68 m (length)×1.72 m (width)× 2.60 m (height), each containing a desk, two chairs, and a computer] were used in this experiment; one for the two odor groups and one for the no-odor group. Finally, participants were then given a full debriefing.

## Data Analysis

For the memory task, a repeated-measures ANOVA was conducted with each participant's number of correctly recalled words, using word (bergamot, peppermint, and neutral) as the within-subjects factor and group (bergamot, peppermint, and no odor) as the between-subjects factor.

Data for the LDT was checked for outliers where RTs for incorrect responses (i.e., defining a real word as a nonword), RTs for nonwords, and RTs less than 200 ms and more than 2,500 ms were removed from the data set, as in previous work (Carreiras and Perea 2002). The remaining latencies were averaged for each participant, separately for bergamot, peppermint, and neutral words. Scores being more than 2 SD away from the mean were regarded as outliers and were, therefore, omitted from any further analysis. On the whole, there were four outliers (one from the bergamot group, three from the peppermint group). For the main analysis, the mean RTs for each participant were subjected to repeated-measures ANOVA, using the within-subjects factor of word (bergamot, peppermint, and neutral) and the between-subjects factor of group (bergamot, peppermint, and no odor).

For the questionnaire data, a correlational analysis was conducted with the familiarity scores and the number of recalled words in the memory task and separately with the familiarity scores and the RTs in the LDT, using Pearson product–moment correlation coefficients.

## Results

### *Free Memory Recall Task*

Analysis revealed a significant main effect of word, $F(2, 84)=16.89$, $p<0.0001$, where more peppermint-associated (4.5±0.2) words were recalled compared to both neutral (3.6±0.1, $p<0.0001$) and bergamot (3.1±0.2), which also differed from one another ($p<0.05$). Importantly, there was a significant group×word interaction, $F(4, 84)=2.46$, $p=0.05$, where mean comparisons revealed that those individuals in the peppermint group recalled more peppermint words compared to bergamot and neutral words (Fig. 2). Separate ANOVAs of each group demonstrated

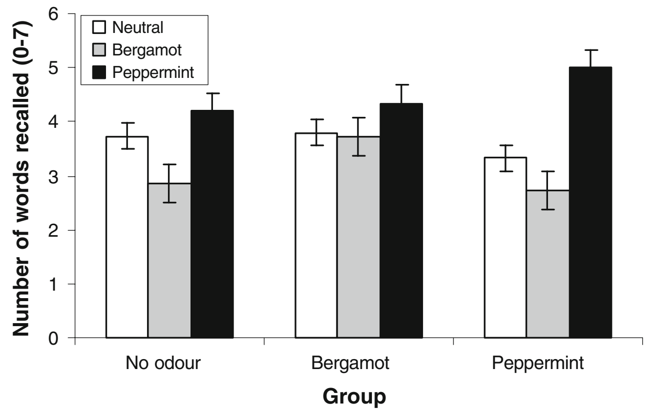


**Fig. 2** Mean (±SEM) number of words recalled depending on word type and odor condition in experiment 2

significant effects of word, in the no odor, $F(2, 28)=5.61$, $p<0.01$, and peppermint, $F(2, 28)=12.98$, $p<0.0001$, groups only, where although those in the no-odor group recalled significantly more peppermint compared to bergamot words ($p<0.05$), only in the peppermint group was there also significantly more peppermint versus neutral words recalled (both $p<0.01$).

### *Lexical Decision Task*

Analysis revealed a significant main effect of word, $F(2, 74)=16.47$, $p<0.0001$, where responses were faster for neutral compared to both peppermint and bergamot words (both $p<0.001$) which also differed from each other ($p<0.01$). The main effect of group failed to reach statistical significance, $F(2, 37)=2.68$, $p=0.08$, though overall RTs were clearly faster for the no-odor (697.03±39.76) group compared to the peppermint (758.47±42.95) and bergamot (827.33±39.76) groups. Against the prediction, the group×word interaction was not significant, $F(4, 74)=1.01$, $p>0.1$, with mean comparisons revealing RTs were no faster when previously experienced odor and word type were congruent (Table 5).

### *Familiarity*

The analysis of odor familiarity revealed no differences between those in the peppermint (71.3±4.4) and bergamot (78.4±4.4) groups, $t(28)=1.07$, $p>0.2$.

**Table 5** Mean (SEM) LDT reaction times by group and word type

| Group | Word type | | |
|---|---|---|---|
| | Bergamot | Neutral | Peppermint |
| No odor | 756.00±52.80 | 660.68±30.64 | 674.42±46.94 |
| Bergamot | 869.72±57.03 | 759.55±33.10 | 852.73±50.71 |
| Peppermint | 826.53±52.80 | 680.76±30.64 | 768.13±46.94 |

*Correlations*

To explore whether memory and attention were associated with differences in familiarity, correlations were conducted on the data for the two odor groups separately. This revealed no significant relationships.

## Discussion

Consistent with the prediction, participants in the peppermint condition recalled significantly more words associated to peppermint compared to bergamot or control words. This pattern was not found with either the no-odor or bergamot groups. The fact that in both experiments 1 and 2 only one of the odors yielded a clear effect of priming implies that the relationship between the odor and associated words is critical in producing this effect. One possibility is that since the words related to peppermint contained more functional words (e.g., toothpaste, gum) compared to a higher number of adjectives for bergamot (e.g., zesty, fresh), it may be that the effects of odors are strongest for odor plus functional words. This gains some support from experiment 1 where both odor-related words contained more functional words compared to adjectives, and although the effects were clearest for those exposed to rosemary, even for those in the jasmine group, more jasmine versus neutral words were recalled which was not seen for bergamot in the experiment here. It is also worth noting that the earlier CDM study (Schab 1990) appeared to use more functional type words (though only three out of seven listed: pie, cider, spice for words related to apple and cinnamon odor), suggesting further that memory for odor-associated words are stronger when words are more functional which possibly also helps strengthen the categorical priming effect.

We can be more confident in stating that, in the present experiment, the observed differences in memory recall cannot be explained by differences in intensity, pleasantness, and familiarity since the two odors were matched on these dimensions. These results confirm and extend the findings of experiment 1 by demonstrating that odors can prime memory for words associated to that odor, even when intensity is controlled. Furthermore, by using an incidental memory task, they show that the effect is not simply limited to explicit memory tasks. The observation that overall memory did not differ between the three groups make it quite probable that the poorer performance of the two odor versus no-odor groups in experiment 1 was due to a general distraction of the task of holding a bottle, rather than any specific odor-impairing effect. This finding is in agreement with research that found no differences in word recognition when an encoding session was accompanied by either constant rose odor or room odor (control) using an olfactometer (Walla et al. 2003).

The results in the LDT revealed that previous exposure to an odor did not influence responses to words associated to that odor, which was against the prediction and previous work (Hermans et al. 1998; Holland et al. 2005). In both of these studies, the odor was either directly inhaled or diffused in the test environment while participants completed the relevant tasks and hence may well account for the divergent findings. It could, therefore, be inferred that merely imagining a recently inhaled odor is an insufficient cue to affect cognition, at least as measured by the LDT. Interestingly, however, research has shown that previous exposure to an odor can influence behavior associated to that odor (Holland et al. 2005). In the final, unusual experiment in the series, that study found that individuals who recently experienced the citrus cleaning odor in one test room compared to those who had not were more likely to remove crumbs away when eating biscuits in an odor-free environment. This suggests (perhaps) that the action of cleaning was stronger for those who had recently smelled the cleaning-associated odor which thereby acted to increase cleaning (crumb removal) behavior in the subsequent task (Holland et al. 2005). However, further work needs to be completed to compare performance on other (more easily interpretable) tasks and using at least two contrasting odors to check for specificity of any effects.

In considering the limitations of the experiment, one might contend that the use of the pleasant/unpleasant categorization of words in the memory task introduced an affective component to the task, possibly introducing unwanted effects. The reason for using such a task was simply to induce a greater/deeper level of processing and has been used in previous studies involving odors (Schab 1990, experiment 3; Walla et al. 2003). Nevertheless, future work should use a more affective neutral method such as asking participants to write down the word.

For the LDT, it could be the case that the words used lacked the association strength to the odor (unlike the memory task) and contributed to the null effect. The rationale for using a different set of words to the memory task was in order to avoid any obvious carry-over effects from that task, i.e., to rule out the possibility that enhanced lexical decision was due to previous word rather than odor exposure. It may also be the case that task order could have influenced LDT findings, since LDT always followed the memory task. Hence, it would be interesting to see if contrasting findings would result in a replication of the LDT but using the words from the memory task. Lastly, the LDT as used in this study may have lacked the necessary sensitivity to detect any odor association effects, especially if one considers the rather unnatural instruction to "imagine that smell from the bottle" combined with a lexical task. It could be that participants did not engage in the imagination part fully and this influenced the findings. On reflection, the mental act of imagining an odor may work better with a task not necessarily using response times as its main measure (e.g., instead use accuracy), else a task that requires individuals to imagine once only for the duration of the task, as the several imagination instructions in this study may well have been overly demanding.

## Conclusion

The two experiments demonstrate that the explicit inhalation of odors can act to influence recall of stimuli associated to that odor. Both experiments showed that the effect was stronger for certain odors which cannot be explained by differences in odor intensity and pleasantness and hence may be due to the strength of the relationship between word and odor. Relevant here are the findings of a study (Dematte et al. 2006) examining the association between certain odors and colors which showed that relatively few odors yielded a consistent choice of colors, with the most highly associated odor/color to be spearmint/turquoise. Hence, the observed effect for peppermint but not bergamot in experiment 2 suggests that, as with odor/color associations, some odor/word associations are simply stronger than other combinations.

More generally, the findings in this study could be seen to provide further experimental evidence of the Proustian effect, i.e., the ability of odors to induce vivid emotional memories (Chu and Downes 2000). The prestudy showed that individuals had relatively intense emotional memories to some of the odors presented. By distilling this into a list of most frequent associations, experiments 1 and 2 demonstrated that odors can act as a potent cue to memory for associated words. It, therefore, appears that individuals' pre-existing associations with the relevant odor here were strong enough to cue memory recall. The findings may also be explained by the encoding specificity principle (Tulving and Thomson 1973) where recall is enhanced to the extent that the cues available at recall match those at encoding. So, recall for the peppermint words was facilitated as these words became associated to the odor of peppermint on a previous occasion. However, this theory seems more appropriate to CDM (e.g., Parker et al. 2001; Schab 1990) where odors are simply an environmental cue to neutral words. Alternatively, the effects could be more related to mood congruent memory theories (e.g., Bower 1981) where the odor activates a network of nodes and emotions connected to the odor-related words. Though such theories are generally applied to actual changes in mood and its congruence to the stimuli recalled (e.g., induction into a happy mood state enhances recall for happy words), hence some modification of the theory would be necessary to accommodate the findings in this study. This could be achieved if we theorize that smelling a particular odor alters some broader aspect of mood/behavior not solely related to positive/negative emotion but is nevertheless congruent with memories linked to that odor which thereby provide preferential access to words related to the odor.

In summary, this research demonstrated that odors are able to cue memory to odor-associated words (relative to nonassociated and neutral words), without the odor being present when the words were originally presented. The finding that some odors had stronger effects than others is interesting and worthy of future research which could also examine participants' cultural origins, eating and cosmetic practices, as these factors may well influence the degree to which associations are attached to certain odors. Connected to this, work has demonstrated that the area an individual resides (city/suburbia/country) can predict the vividness of memories associated to popcorn (higher for city dwellers) and fresh-cut grass (higher for country residents) (Herz 2004). It would, therefore, be fruitful for additional work to examine more specifically how these factors help predict the influence of odor on odor-associated behavior.

## References

Aggleton JP, Waskett L (1999) The ability of odours to serve as state-dependent cues for real-world memories: can Viking smells aid the recall of Viking experiences? Br J Psychol 90:1–7

Bower GH (1981) Mood and memory. Am Psychol 36(2):129–148

Carreiras M, Perea M (2002) Masked priming effects with syllabic neighbors in a lexical decision task. J Exp Psychol Hum Percept Perform 28(5):1228–1242

Chu S, Downes JJ (2000) Odour-evoked autobiographical memories: psychological investigations of Proustian phenomena. Chem Senses 25(1):111–116

Dematte ML, Sanabria D, Spence C (2006) Cross-modal associations between odors and colors. Chem Senses 31(6):531–538

Doty RL, Snyder PJ, Huggins GR, Lowry LD (1981) Endocrine, cardiovascular, and psychological correlates of olfactory sensitivity changes during the human menstrual-cycle. J Comp Physiol Psychol 95(1):45–60

Francis WN, Kucera H, Mackie AW (1982) Frequency analysis of English usage: lexicon and grammar. Houghton-Mifflin, Boston

Green MW, McKenna FP (1993) Developmental onset of eating related colour-naming interference. Int J Eat Disord 13(4):391–397

Hermans D, Baeyens F, Eelen P (1998) Odours as affective-processing context for word evaluation: a case of cross-modal affective priming. Cogn Emot 12(4):601–613

Herz RS (1997) Are odors the best cues to memory? A cross-modal comparison of associative memory stimuli. Paper presented at the International Symposium on Olfaction and Taste XII, San Diego, California, 7–12 July

Herz RS (2004) A naturalistic analysis of autobiographical memories triggered by olfactory visual and auditory stimuli. Chem Senses 29(3):217–224

Herz RS, Cupchik GC (1992) An experimental characterization of odor-evoked memories in humans. Chem Senses 17(5):519–528

Herz RS, Engen T (1996) Odor memory: review and analysis. Psychon Bull Rev 3(3):300–313
Holland RW, Hendriks M, Aarts H (2005) Smells like clean spirit. Psychol Sci 16(9):689–693
Ilmberger J, Heuberger E, Mahrhofer C, Dessovic H, Kowarik D, Buchbauer G (2001) The influence of essential oils on human attention. I: alertness. Chem Senses 26(3):239–245
Laird DA (1935) What can you do with your nose? Sci Mon 41 (2):126–130
Morrin M, Ratneshwar S (2003) Does it make sense to use scents to enhance brand memory? J Mark Res 40(1):10–25
Parker A, Waterman M, Gellatly A (2000) Effect of environmental context manipulations on explicit and implicit memory for categorised and random words. Cah Psychol Cogn 19(1):111–132
Parker A, Ngu H, Cassaday HJ (2001) Odour and Proustian memory: reduction of context-dependent forgetting and multiple forms of memory. Appl Cogn Psychol 15:159–171
Schab FR (1990) Odors and the remembrance of things past. J Exp Psychol Learn Mem Cognit 16:648–655
Schifferstein HNJ, Blok ST (2002) The signal function of thematically (In) congruent ambient scents in a retail environment. Chem Senses 27(6):539–549
Stafford LD, Yeomans MR (2005) Caffeine deprivation state modulates coffee consumption but not attentional bias for caffeine-related stimuli. Behav Pharmacol 16(7):559–571
Sugawara Y, Hino Y, Kawasaki M, Hara C, Tamura K, Sugimoto N et al (1999) Alteration of perceived fragrance of essential oils in relation to type of work: a simple screening test for efficacy of aroma. Chem Senses 24(4):415–421
Tulving E, Thomson DM (1973) Encoding specificity and retrieval processes in episodic memory. Psychol Rev 80(5):352–373
Walla P, Hufhagl B, Lehrner J, Mayer D, Lindinger G, Imhof H et al (2003) Olfaction and depth of word processing: a magneto-encephalographic study. NeuroImage 18(1):104–116