Chem. Senses 36: 29–41, 2011
doi:10.1093/chemse/bjq095
Advance Access publication October 8, 2010

Odor Recognition Memory as a Function of Odor-Naming Performance

Robert A. Frank, Konstantin Rybalsky, Melinda Brearton and Erica Mannea

Department of Psychology, University of Cincinnati, Cincinnati, OH 45221-0367, USA

Correspondence to be sent to: Robert A. Frank, Office of the Dean, McMicken College of Arts and Sciences, ML 367, University of Cincinnati, Cincinnati, OH 45221-0367, USA. e-mail: robert.frank@uc.edu

Accepted August 22, 2010

Abstract

A series of experiments sought to clarify the relationship between odor naming and memory by manipulating odor label availability during a dual naming–memory task. Experiment 1 demonstrated that recognition memory and odor naming were both better when the naming task provided participants with odor label alternatives. Consistent and correct odor naming was associated with nearly perfect memory, whereas inconsistent or incorrect naming was associated with very weak memory if any at all. Experiment 2 showed that the availability of odor labels was effective at improving memory only if labels were available at both memory encoding and retrieval, suggesting that the labels were aiding memory by improving the identification of the odors. Odor naming was manipulated in Experiment 3 by varying the number of available labels from 4 to 16 during each odor-naming trial. As found in the previous experiments, naming and memory were strongly related in each of the labeling conditions. Experiment 4 showed that corrective naming feedback produced better memory performance but only when the feedback led to correct odor naming. It was concluded that perceptual processes related to matching olfactory input to acquired, multidimensional representations of odors play a critical role in both odor naming and episodic memory.

Key words: feedback, human olfaction, odor identification, olfactory cognition

Introduction

The relationship between odor naming (thought to reflect semantic memory) and odor recognition memory (thought to reflect episodic memory) has been the topic of considerable interest to investigators studying odor and flavor perception (Engen and Ross 1973; Lawless and Cain 1975; Lyman and McDaniel 1986, 1990; Cain and Potts 1996; Jehl et al. 1997; Lehrner et al. 1999; Bhalla et al. 2000; Zucco 2003; Lumeng et al. 2005). Understanding this relationship is important to our understanding of the fundamental processes underlying olfactory perception and cognition. In addition, it contributes to a fuller appreciation of the nature of flavor and fragrance expertise (Parr et al. 2004; Valentin et al. 2007) and may aid in the diagnosis and treatment of neurodegenerative disease because these disorders are characterized by early deficits of both semantic and episodic odor memory (Murphy et al. 1999; Ponsen et al. 2004; Wilson et al. 2007; Boesveldt et al. 2008; Djordjevic et al. 2008; Ross et al. 2008).

Published studies have reached conflicting conclusions about the relationship between odor naming and memory. Although some studies report no association (e.g., Engen and Ross 1973; Lawless and Cain 1975; Parr et al. 2002, 2004; Moller et al. 2004), significant and even strong correspondence between the ability to name and remember odors has been reported in many (Rabin and Cain 1984; Lyman and McDaniel 1986; Cain and Potts 1996; Lesschaeve and Issanchou 1996; Larsson and Backman 1997; Lehrner et al. 1999; Lumeng et al. 2005; Valentin et al. 2007; Yeshurun et al. 2008; Olsson et al. 2009). We sought to clarify the relationship by focusing on recognition memory under a variety of conditions known to affect odor naming. By examining the pattern of covariation between naming and memory, we hoped to gain insight into the relationship between semantic and episodic odor memory processes.

Experiment 1

One of the most dramatic ways to affect odor identification performance is to provide people with alternative labels for an odor they are trying to name. For familiar odors, identification performance usually reaches 50% or less when people are asked to generate their own odor labels but typically improves to 85% or better when alternative odor labels are provided (Cain and Krause 1979; Doty et al. 1984; Engen

1987). Pilot studies in our laboratory using both odor and flavor stimuli demonstrated an improvement in both odor naming and recognition memory when alternative odor labels were available (Horning et al. 2006; Bailie et al. 2007). Experiment 1 sought to replicate these results and provide a baseline for follow-up studies. It was predicted that both odor naming and recognition memory would improve when odor label alternatives were available.

Materials and methods

Participants

Fifty adults were recruited from University of Cincinnati undergraduate psychology courses. Age ranged from 18 to 38 years (mean = 19.1 years), and the sample was 86% female. All participants provided written informed consent and filled out a brief questionnaire providing basic demographic information. Participants reported being generally healthy and were excluded if they noted a history of severe asthma or a loss of the sense of smell. Participants were tested individually on the olfactory measures and received course credit for their participation. The study was reviewed and approved by the University of Cincinnati Institutional Review Board.

Test apparatus

A concurrent odor naming and recognition memory test similar to that described by Rabin and Cain (1984) and Lumeng et al. (2005) was employed. Odor stimuli were delivered by a computer-controlled, air-dilution olfactometer designed by Osmic Enterprises, Inc. (Hastings and Wilson 2004). The olfactometer ensured consistent stimulus delivery and timing under computer control. Airflow (30 cm^3/min) was filtered through a charcoal tube and directed to the sampling port for background flow or through the odor reservoirs for stimulus presentation. The participant was instructed to position his or her nose approximately 3.0 cm away from the sampling port. Once prompted by the computer, participants sniffed the odorized air ad libitum from the sampling port for up to 5 s. A mouse click by the participant initiated odor presentation through the olfactometer, and then the computer program prompted participant responses.

Stimuli

During test development, odor-naming data were collected from young adults using a wide range of odorants with the aim of creating a test composed of easily nameable odors (Bailie et al. 2007; Mannea et al. 2008). Eighteen odor stimuli were selected for the current study based on this process (see Supplementary appendix for a list). The odorants were chosen to be highly familiar and likely to be named in a relatively uniform way by most study participants. The odors were divided into 2 sets—one presented during both Phase 1 (encoding) and Phase 2 (retrieval) of the test (these are referred to as ''old'' odors) and one set presented only during Phase 2 (referred to as ''new'' odors). Efforts were made in preliminary testing to balance the old and new odorant sets based on naming ability, pleasantness, as well as the diversity of odor quality categories (i.e., fruits, spices, and nonfoods) in each set. The same set of odors served as old or new stimuli for all participants, and the same stimulus order was used for all testing.

Preliminary work also focused on the selection of normative labels for the odorant stimuli as well as alternative labels that would serve as foils in the forced-choice odor-naming task. Response alternative labels were selected for each of the odorants by choosing labels from 4 conceptual categories: fruits (e.g., ''apple'' and ''banana''), spices (e.g., ''cinnamon'' and ''clove''), foods (e.g., ''peanut butter'' and ''popcorn''), and nonfoods (e.g., ''tar'' and ''leather''). A response alternative from each of these categories, including the normative odor label (i.e., the label most often assigned to the odor) was combined on each trial with each odor stimulus. This approach is employed in 2 common odor-naming tests, the University of Pennsylvania Smell Identification Tes and Sniffin' Sticks (Doty et al. 1984; Hummel et al. 2001). Normative labels scored as correct for 1 odor were occasionally included among the response alternatives for another odor so that a particular label could be a correct or incorrect response depending on the trial. In addition, the sets of 4 response alternatives used in Phase 1 of the test were altered in Phase 2. The listing order of the response alternatives associated with the odors in Phases 1 and 2 was changed as well as the combination of labels used for each odor. All this was done so that the set of response alternatives could not provide information about whether an odor had been presented in Phase 1.

Procedure

Participants self-administered the test using a computer software program that presented instructions and prompted participants to sniff and respond. Before data collection began, each participant was given an opportunity to become familiar with the testing program. Participants were told they would be naming and remembering odors during the test. They were told to guess when they were not sure about an odor's name. After familiarizing themselves with the instructions, participants engaged in a practice trial to insure that they understood the procedures and the operation of the testing system. Odor naming always preceded the old/new judgments in Phase 2 of the task.

Participants completed 2 test phases after they were randomly assigned to 1 of 2 experimental groups. In Phase 1, both groups named 9 odor stimuli. One group was provided with 4 odor name alternatives for each odor during naming (as described in the Stimuli section), whereas the other group self-generated names without the aid of these alternatives. No feedback on naming performance was provided to participants. Phase 1 was followed by a 10-min retention interval. In Phase 2, participants were presented with 18 odor stimuli one at a time: the 9 from Phase 1 plus 9 new odors. They first named each odor as in Phase 1, one group again given odor label alternatives and one group self-generating labels. Each odor was also categorized as old or new. The order of stimulus presentation was randomized for the old and new odors.

Results

Odor-naming performance was evaluated during the first and second phases of the experiment. The response to each of the stimuli was analyzed for correctness based on the normative odor label (e.g., ''garlic'' for garlic oil) and was categorized using a ''stringent'' criterion, whereby participant responses were categorized as correct only for providing the exact normative response. Mean proportion of correct odor-naming responses is shown in Figure 1. To assess whether performing the naming task in Phase 1 had an effect on overall odor naming during Phase 2, performance in each phase was compared with and without label alternatives in a 2 (phase) × 2 (labeling condition) design using a repeated measures analysis of variance (ANOVA). As expected, providing alternative odor labels had a significant effect on naming accuracy ($F_{1,48} = 355$, $P < 0.001$), but no effect of phase or phase by labeling condition interaction was observed. Thus, naming the odors during Phase 1 did not improve naming performance in Phase 2.

Providing odor labels enhanced recognition memory performance as shown in Figure 2. Providing labels was associated with a significant increase in overall proportion of correct memory responses ($t_{48} = 9.6$, $P < 0.005$). Label-associated memory enhancement was also observed for the proportion of hits ($t_{48} = 6.9$, $P < 0.01$) and correct rejections ($t_{48} = 4.9$, $P < 0.01$).

The relationship between odor naming and memory was evaluated using 2 measures of labeling performance. Correct labeling was defined as selection of the normative odor label, whereas consistent labeling was defined as selection of the same name irrespective of whether it was the correct or incorrect normative label. These measures have been used in previous investigations of odor identification and memory (Rabin and Cain 1984; Lehrner et al. 1999; Lumeng et al. 2005). Following the approach of Rabin and Cain (1984), the data were analyzed on a trial-by-trial basis (rather than an individual participant basis). Separate analyses were performed for the set of old and new odors because only the old odors could be assessed for consistency. The relationship between naming and memory performance for the old odors is shown in Table 1.

The pattern of results shown in Table 1 is very clear. For both labeling conditions, memory responses were almost always correct when the odor was named accurately twice. Memory was very poor if the odor was incorrectly named in Phase 1 and then correctly named in Phase 2, or vice versa. Consistent naming was almost always associated with

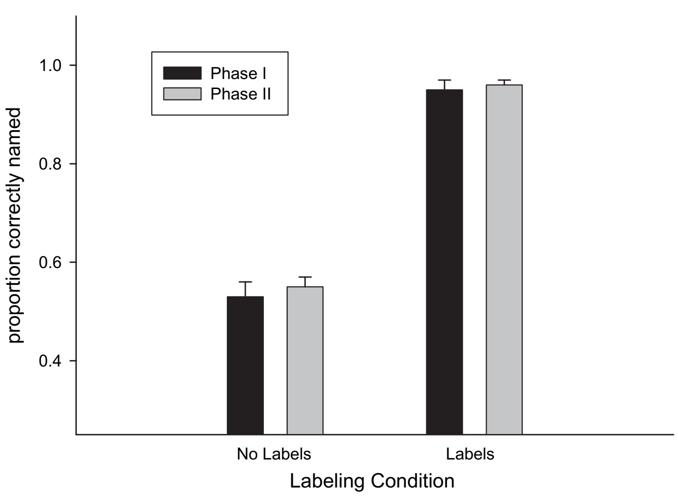

Figure 1 The effect of label alternatives on naming performance.

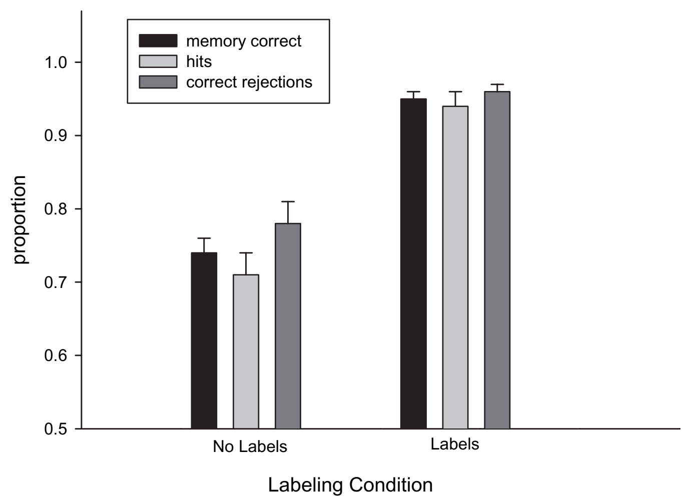

Figure 2 The effect of label alternatives on recognition memory.

Table 1 Percent memory correct as a function of naming accuracy and consistency for the "old" and "new" odors in Experiment 1

	No labels	Labels
Old odors		
Named correctly twice	93	98
Named correctly Phase 1 only	29	0
Named correctly Phase 2 only	18	22
Named incorrectly twice	70	67
Named consistently	94	97
Named inconsistently	44	20
New odors		
Named correctly	82	97
Named incorrectly	76	83

correct memory responses, whereas there was no evidence for remembering when naming was inconsistent. The finding that seems out of place is the memory performance associated with naming an odor incorrectly twice. Across labeling conditions, the memory performance on these trials was about 70% correct. Insight into this finding was gained by noting that memory performance was correct on 58 of 61 trials (95%) when incorrect naming was consistent (i.e., the same incorrect label was used twice). This compares to 43 of 82 memory correct trials (52%) when memory was incorrect twice and also inconsistent (i.e., participants used 2 different incorrect labels during the test). This same pattern was reported by Cain and Potts (1996) in their study of odor naming and memory. Clearly, consistent responding is more important than correct responding as a predictor of memory performance. This impression was verified by logistic regression analysis employing generalized linear modeling and the generalized estimating equations (GEE) program of SPSS 16. This approach allowed the data from individual memory trials to be predicted in a mixed model where odor stimulus was a repeated measure and labeling condition, naming consistency, and naming accuracy were used as other predictors. For old odors, the model incorporating odor stimulus and consistency provided the best fit based on the corrected quasi-likelihood under independence model criterion (QICC) goodness of fit measure (labeling condition was not significant). The Wald chi-square value for odor stimulus was $\chi^2(8) = 36$ ($P < 0.001$), and for consistency, it was $\chi^2(1) = 113$ ($P < 0.001$). This analysis confirms that naming consistency was a very powerful predictor of memory responses for the old odors. The significant odor stimulus effect simply reflects the fact that some odors were more easily remembered than others.

The naming–memory relationships for the new odors are shown at the bottom of Table 1. As observed with the old odors, accurate naming was associated with strong memory performance. However, in contrast to the old odor findings, memory responses for the new odors were correct on 76% of the trials despite incorrect naming. The weaker relationship between correct naming and memory performance was reflected in a logistic regression analysis for the new odors. The best-fitting logistic regression model included odor stimulus, labeling condition, and naming accuracy. The Wald chi-square value was $\chi^2(8) = 32$ ($P < 0.001$) for odor stimulus and $\chi^2(1) = 13$ ($P < 0.001$) for labeling condition, but the effect for naming accuracy was only marginally significant ($\chi^2(1) = 3$, $P < 0.10$). Despite the marginal significance of naming accuracy, the regression model fit was substantially better when naming accuracy was included as a variable indicating that naming accuracy did provide predictive power.

Discussion

The results of Experiment 1 replicate those observed previously (Horning et al. 2006; Bailie et al. 2007). Providing odor label alternatives during a dual odor-naming/recognition memory task improved both naming accuracy and recognition memory. In addition, consistent with past findings (Rabin and Cain 1984; Cain and Potts 1996; Lehrner et al. 1999; Lumeng et al. 2005), naming consistency was an excellent predictor of memory performance.

It is noteworthy that the percent memory correct trials for the no-labels condition (74%) was very similar to performance on the recognition memory task in past studies when participants did not explicitly name the odors (73% and 78% in 2 studies using the same odor set) (Brearton et al. 2008; Brearton and Frank 2010). This finding indicates that the act of explicitly assigning a verbal label to an odor does not necessarily improve recognition memory performance, a conclusion also reached by Lawless and Cain (1975). By contrast, if the experimenter provides a single veridical odor name for each odor at encoding, recognition memory improves (Lyman and McDaniel 1990). Providing the veridical name is roughly equivalent to reducing the labels from 4 possible names (as done in the current study) to the one correct name. In contrast to the finding reported here and to those of Lawless and Cain (1975), Lyman and McDaniel (1986) reported improved recognition memory when odor names and definitions were self-generated by participants at encoding (irrespective of their ‘‘correctness’’). It is noteworthy that this effect of self-generated labels was modest and expressed as a decrease in false alarms, not an enhancement of hit rate. Taken together, the available evidence provides little support for the idea that the mere act of ‘‘attempting’’ to name odors improves episodic odor encoding.

Several explanations for the different pattern of results for the old and new odors can be considered. It is possible that episodic memory or decision processes related to a past event (e.g., presentation of an old odor) may differ from those involved in remembering that an event did not occur (e.g., recognizing an odor as new). Another possibility is that the apparent evidence for memory on the incorrect naming trials results from a response bias. Specifically, this bias would be a tendency to respond new when the participant has difficulty identifying an odor. Some evidence for this bias was observed. The response new was made on 69% of the trials when naming was inconsistent or incorrect. When naming responses were consistent (for old odors) or correct (for new odors), the response new was made on 45% of the trials—much closer to the value of 50% that represents unbiased responding. A bias to respond new to unidentified odors would lead to correct memory responses for new stimuli and provide apparent evidence for recognition memory. Jonsson and Olsson (2003) and Jonsson et al. (2005) reported that people usually can provide very little information about odors they cannot name. When the identity of an odor is unclear, the response ‘‘I did not smell this odor before’’ (i.e., responding new) seems more appropriate than replying old for an unrecognized odor because participants may be reluctant to report they experienced the odor previously but cannot say ‘‘what it is.’’ This strategy would result in a bias to respond new to the poorly identified odor. This possibility of a new response bias clouds the interpretation of correct memory responses for trials on which naming was inconsistent or incorrect. Unfortunately, unlike old odors, the new odors cannot be analyzed for consistent responding in the current study because only one naming opportunity was provided. Thus, the new odors cannot be corrected for consistent responses when participants use nonnormative odor labels. This could contribute to an apparently greater proportion of memory correct responses associated with incorrect odor naming.

Experiment 2

Three explanations for the effects of the labels on episodic memory in Experiment 1 can be considered. The labels may operate during memory encoding by providing a verbal component to the episode, thereby making it easier to retrieve at a later time. If enhanced encoding accounts for the effects of labels, memory improvement should be obtained if the labels are available only during Phase 1 (encoding) of the testing procedure.

A second possibility is that the labels improved retrieval of episodic memories by supporting a more effective strategy for searching memory during Phase 2 (retrieval). Providing alternative odor labels at the time of memory retrieval may allow the subject to focus on memories restricted to the odor set specified by the labels, thereby improving the probability of retrieving the memory. If the labels act to enhance retrieval processes, providing labels only during Phase 2 should produce improved recognition memory.

A third possibility is that label alternatives enhance odor memory not by improving encoding or retrieval but rather by supporting odor identification. The labels may aid in matching an odor being experienced to a stored olfactory representation, something akin to the concept of the "odor object" proposed by Stevenson and Wilson (2007). Once an odor object is identified and/or categorized, it is much more readily remembered. This hypothesis would explain 2 important observations from Experiment 1: the strong association between odor naming and recognition memory and the fact that naming an old odor correctly only once (either at encoding only or at retrieval only) was not associated with improved memory performance. If this perspective is correct, the memory-enhancing effects of odor label alternatives may disappear if they are provided only during encoding or retrieval.

Odor label alternatives were made available during only Phase 1 or only Phase 2 in Experiment 2. Otherwise, the details of the experimental procedure were identical to Experiment 1. If the memory-enhancing effects of the labels occur at encoding, providing labels at Phase 1 should improve recognition memory. If the effects operate at retrieval, the enhancement should be observed when the labels are available only at Phase 2. If the labels improve memory because they facilitate matching olfactory input to stored representations akin to odor objects, they may need to be available during both Phases 1 and 2.

Materials and methods

Participants

Fifty adults were recruited from University of Cincinnati undergraduate psychology courses and ranged in age from 18 to 28 years (mean = 19.3 years). The sample was 82% female. Participants reported being generally healthy and were excluded if they noted a history of severe asthma or a loss of the sense of smell. Twenty-five individuals served in each of the 2 experimental conditions. The other experimental details were as described in Experiment 1.

Stimuli, apparatus, and procedures

These details of the experiment were as described in Experiment 1 with the following exceptions. One group of participants was provided with 4-alternative odor labels during Phase 1 but self-generated names during Phase 2. The other group self-generated names during Phase 1 but then received 4-alternative labels during Phase 2.

Results

The data were screened and analyzed as described in Experiment 1. A one-between (phase of label availability), one-within (phase of testing) ANOVA revealed no main effects for phase of label availability or phase of testing on odor naming ($P > 0.15$), but a significant interaction was observed ($F_{1,48} = 484$, $P < 0.001$). As expected, the availability of odor label alternatives produced superior naming performance whenever the labels were available irrespective of the phase of the test (see Figure 3). The performance levels were very similar to those observed in Experiment 1 when labels were (or were not) available.

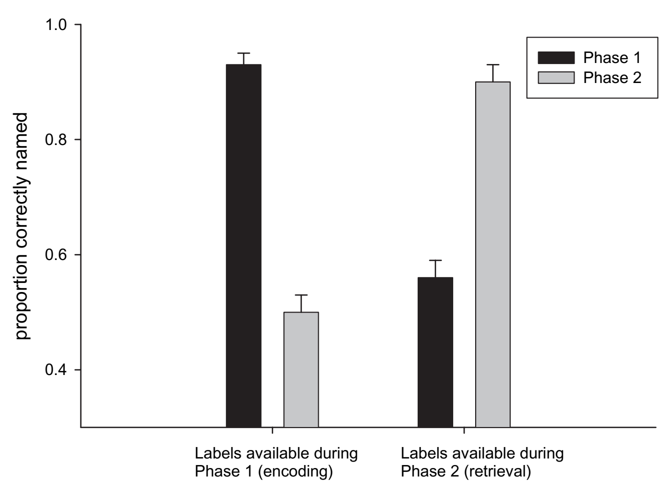

Figure 3 The effects of the availability of odor label alternatives in Phase 1 or 2 on naming performance in Experiment 2.

Recognition memory performance for the combined data of Experiments 1 and 2 is shown in Figure 4. One-way, between-subject ANOVAs were performed for percent memory correct, hits and correct rejections using data from the 2 conditions of Experiment 1 and the 2 conditions of Experiment 2 combined. The analyses revealed significant differences in percent recognition memory correct between the conditions, $F_{3,96} = 30.5$, $P < 0.001$. Post hoc paired comparisons were made using Tukey's honestly significant difference technique (HSD) test with P set at 0.05. The test revealed that memory performance was significantly better in the condition where labels were available during Phases 1 and 2 as compared with all the other conditions. No significant differences in percent memory correct were observed among the other 3 groups (all P values > 0.05). An identical pattern was observed for correct rejections. The hits ANOVA revealed a somewhat different pattern. Similar to memory correct and correct rejections, a significant effect of condition was observed, $F_{3,96} = 20.71$, $P < 0.001$, and Tukey's HSD corrected post hoc comparisons revealed that participants had significantly more hits when labels were available during both phases of testing. Participants who received verbal labels only during the second phase of testing produced significantly fewer hits than participants in the other 3 groups.

The association between naming performance and memory for old and new odors is shown in Table 2. The same pattern was observed regardless of whether labels were available during Phase 1 or 2. As found in Experiment 1, when naming was correct twice or consistent, memory was nearly perfect. When naming was incorrect or inconsistent, there was no evidence for recognition memory. The response patterns for the new odors are similar to those observed in Experiment 1.

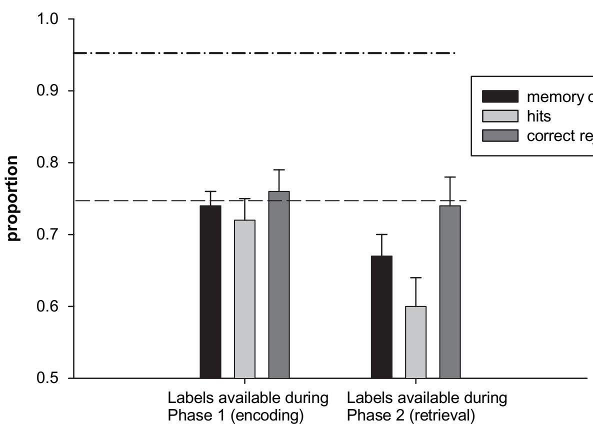

Figure 4 Recognition memory performance for the labeling conditions of Experiment 2. The dashed line shows mean memory correct performance from Experiment 1 for the condition where no labels were available while the dash-dotted line shows mean performance with labels available during both phases of testing.

A summary of the results from Experiments 1 and 2 is shown in Table 3. The relationship between naming and recognition memory was explored statistically using logistic regression. The data from Experiments 1 and 2 were combined and subjected to generalized linear modeling using the GEE program of SPSS 16. This approach allowed the data from individual memory trials to be predicted in a mixed model where odor stimulus was a repeated measure and labeling condition, naming consistency, and naming accuracy were used as other predictors. The data from the old and new odors were modeled separately. Labeling condition included 2 levels—the 2 used in Experiment 1 and the 2 used in Experiment 2. For old odors, the model incorporating odor stimulus and consistency provided the best fit based on the QICC goodness of fit measure. The Wald chi-square value for odor stimulus was $\chi^2(8) = 49$ ($P < 0.001$), and for consistency, it was $\chi^2(1) = 180$ ($P < 0.001$). This analysis

Table 2 Percent memory correct as a function of naming accuracy and consistency for the "old" and "new" odors in Experiment 2

	Labels—Phase 1	Labels—Phase 2
Old odors		
Named correctly twice	94	94
Named correctly Phase 1 only	52	0
Named correctly Phase 2 only	50	50
Named incorrectly twice	43	25
Named consistently	94	92
Named inconsistently	51	47
New odors		
Named correctly	91	76
Named incorrectly	69	57

Table 3 The relationship between odor naming and memory across the conditions of Experiments 1 and 2

	% Memory correct for		
	Labels provided	Consistent naming	Inconsistent naming
Old odors	Both Phases	94	51
	None	92	47
	Phase 1 only	94	44
	Phase 2 only	97	20
New odors	Both Phases	82	76
	None	97	83
	Phase 1 only	91	69
	Phase 2 only	76	57

confirms that naming consistency was a very powerful predictor of memory responses for the old odors.

The best-fitting logistic regression model for the new odors included odor stimulus, labeling condition, and naming accuracy. The Wald chi-square value was $\chi^2(8) = 82$ ($P < 0.001$) for odor stimulus, $\chi^2(3) = 25$ ($P < 0.001$) for labeling condition, and $\chi^2(1) = 15$ ($P < 0.001$) for naming accuracy. This suggests that consistency was a more powerful predictor of memory for the old odors as compared with the predictive power of accuracy for new odors, a pattern that seems evident in Table 3. This impression was confirmed by calculating the odds ratio for consistent naming of the old stimuli (22.3) compared with the odds ratio for accurate naming of the new stimuli (2.7).

Discussion

Making the odor labels available only during encoding or retrieval did not enhance recognition memory performance over providing no labels at all. Labels needed to be present during both phases of testing to enhance recognition memory performance. This result provides *no* support for the idea that the memory-enhancing effects of the labels are mediated primarily by improved encoding or retrieval processes per se. The effect of the labels on episodic odor memory appears to be mediated by a facilitation of olfactory pattern matching.

The trial-by-trial, cross-tabulation results support the conclusions of Experiment 1. Successful and consistent odor naming was associated with high levels of memory performance for both old and new odors, and evidence for a bias to respond new when an odor has not identified was observed. Inconsistently named old odors and incorrectly named new odors were associated with the incorrect response new on 58% of the trials.

Experiment 3

How do the odor labels improve odor naming and recognition memory? One possibility is that the labels provide a context for memory search processes much like occurs with a multiple choice testing format often used for learning assessment (Haladyna et al. 2002; Butler and Roediger 2008). Providing a list of possible ''answers'' allows an individual to narrow the search for matches between a current olfactory experience and olfactory patterns stored in memory. This greatly simplifies a task, whether it is identifying odors or recall of facts studied in anticipation of academic test. Stevenson and Wilson (2007) refer to the multidimensional memory representation of the odor as the odor object. They speculate that the meaningfulness of an olfactory experience is closely tied to its categorization as an odor object. Contextual stimuli, such as odor label alternatives, may support matching of current olfactory input to stored olfactory experiences and thereby aid in identification of the odor object. In other words, the context supports successful access to odor representations in memory.

We speculate that successful matching of the odor experience to an odor object is critical to episodic odor memory. The meaning of an olfactory experience must be determined before it can be effectively remembered. Knowing what odor is being experienced (as evidenced by successful naming) is necessary for both encoding and retrieving episodic odor memory, and so manipulations that enhance or degrade odor naming should have a similar effect on odor recognition memory.

These ideas were tested in Experiment 3 by investigating the effect of manipulating the number of odor label alternatives on odor naming and recognition memory performance. It has been shown that performance on multiple choice tests deteriorates as the number of response alternatives increases (Roediger and Marsh 2005), presumably because the advantage of directing attention to a small set of response options is lost as the alternatives increase. If the comparison to multiple choice testing is apt, providing more odor response alternatives also should erode the positive effects of providing labels on odor naming and, by extension, produce a decline in recognition memory performance.

Materials and methods

Participants

A total of 100 participants recruited from introductory psychology courses completed the experiment. Age ranged from 18 to 38 years (mean = 20.3 years), and the sample was 77% female. Each participant completed a questionnaire about general health and past or present olfactory problems. Participants reported being generally healthy and were excluded if they noted a history of severe asthma or a loss of the sense of smell. The experimental procedures were approved by the University of Cincinnati Institutional Review Board, and written informed consent was obtained for all study participants.

Stimuli

The 20 odor stimuli used for testing are shown in the Supplementary appendix. The set is identical to that used in Experiments 1 and 2 within the addition of 2 odorants, lemon and cinnamon.

Procedure

The dual odor-naming/recognition memory test used in the labels condition of Experiment 1 was used in Experiment 3 with the following modifications. Twenty-five participants were assigned to each of 4 conditions. The conditions differed only in the number of alternative names provided for each odor presented during the identification task. Four, 8, 12, or 16 odor name alternatives were provided with each odor stimulus in the test conditions. The odor label alternatives were available during both Phases 1 and 2. The odor name most commonly assigned to a stimulus (its normative or ‘‘correct’’ name) was always included as a response alternative. In the 4-alternative condition, this normative name was combined with 3 foils chosen to be qualitatively dissimilar to the target odor as described for Experiments 1 and 2. The 8-alternative condition combined 7 foils with the normative label, the 12-alternative used 11 foils, and the 16 used 15 foils. The foils used for the 8-, 12-, and 16-alternative conditions combined different sets of labels used for the 4-alternative condition to generate sets of 8, 12, and 16 alternatives. Care was taken to avoid including easily confused odor labels (e.g., garlic and onion together) in a set of response alternatives.

Results

One-way (number of odor labels) ANOVAs were performed comparing correct naming and memory responses, as well as memory hits and correct rejections. The effect of number of labels was significant for correct naming ($F_{3,96}$ = 29.9, P < 0.001), memory correct ($F_{3,96}$ = 12.7, P < 0.001), hits ($F_{3,96}$ = 14.7, P < 0.001), and correct rejections ($F_{3,96}$ = 4.0, P < 0.01). As shown in Figure 5, the proportion of correct naming and memory responses decreased as the number of response alternatives increased.

The relationship of odor naming to odor memory across the labeling conditions is shown in Table 4. The pattern of results is very similar across the labeling conditions. Logistic regression of memory performance was performed using the generalized linear modeling approach and GEE as described in Experiment 2. For old odors, the model incorporating odor stimulus and consistency provided the best fit based on the QICC goodness of fit measure. The Wald chi-square value for odor stimulus was $\chi^2(9) = 23$ (P < 0.01) and for consistency, it was $\chi^2(1) = 216$ (P < 0.001). For the new odor analysis, one odor (lemon) was dropped because 100% of the memory responses were correct for this odor. The errorless performance created problems with the GEE calculations due to lack of variation. Excluding lemon, the best fit was provided by a model that included odor stimulus (Wald $\chi^2(8) = 21$, P < 0.01) and naming accuracy (Wald $\chi^2(1) = 47$, P < 0.001).

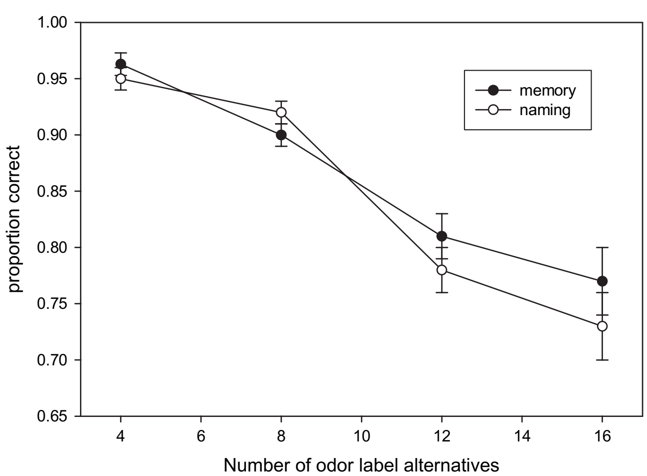

Figure 5 Proportion correct memory and naming responses as a function of the number of odor label alternatives in Experiment 3.

Discussion

As predicted, the number of response alternatives affected odor-naming and recognition memory performance in tandem. In addition, the findings of Experiment 3 replicate those of Experiments 1 and 2. Naming consistency and accuracy were powerful predictors of memory responses. Experiment 3 provides additional evidence for the bias to respond new when odors are not correctly identified. The response new was given on 73% of the trials when naming was inconsistent or incorrect. The effect of the response bias on memory assessment is substantially eliminated by collapsing across responses to old and new stimuli in Table 4.

Experiment 4

We have hypothesized that providing odor labels improves memory by aiding the process of odor object identification. If true, other manipulations that facilitate the identification of odor objects should improve recognition memory. For example, odor expertise would be expected to aid in the identification of odor objects familiar to the expert and should also improve recognition memory. To the extent that beer provides an example of an odor object, this prediction has been shown to be true (Valentin et al. 2007).

Past studies have shown that corrective feedback improves odor naming (Desor and Beauchamp 1974; Schemper et al. 1981; Cain 1982: Eskenazi et al. 1983; Cain et al. 1998). The

Table 4 The relationship between odor naming and memory for “old” and “new” odors across conditions in Experiment 3

	% Memory correct for		
	Labels	Consistent naming	Inconsistent naming
Old odors	4	99	19
	8	99	33
	12	94	37
	16	99	22
New odors	4	96	58
	8	94	79
	12	91	75
	16	90	78

feedback presumably supports improved naming performance by facilitating the match between the currently experienced odor percept and a stored odor representation that includes verbal information. Experiment 4 assessed the effect of corrective odor-naming feedback on recognition memory. It was predicted that when corrective feedback is effective in improving naming performance, it will also improve recognition memory but that when corrective feedback does not improve naming it will not improve memory.

Materials and methods

Participants

Fifty adults, aged 18–36 years (mean = 19.6 years), participated in this study. The sample was 70% female. Participants were recruited from University of Cincinnati introductory psychology courses and received course credit for their involvement in the study. Participants reported being generally healthy and were excluded if they noted a history of severe asthma or a loss of the sense of smell.

Procedure

Participants were tested in 2 groups, a control group ($n = 25$) and a feedback group ($n = 25$). The control group completed the dual odor-naming/memory test used in Experiment 3 in the 16–response alternative condition. The feedback group was administered the same test except that corrective feedback was provided for odor naming during the first phase of the test. The 16-alternative odor labels were available during both phases of testing. The feedback consisted of either informing the participant that the response was correct or informing him or her that the response was incorrect and providing the correct label. All other aspects of the tests were identical to those described in Experiment 3.

Results and discussion

Table 5 provides the distribution of responses for old odors as a function of naming and memory performance for the control and feedback groups. As found in the previous experiments, memory was excellent (99% correct) for both groups when naming was correct during both the first and second phases of testing. Likewise, for both groups, memory was poor when naming was incorrect for both phases and when it was correct during encoding but incorrect at retrieval. The critical comparison is between the feedback and control group when naming is incorrect in Phase 1 but correct in Phase 2. This comparison allows for an assessment of the impact of effective naming feedback. The pattern for the control group was similar to that found previously with inconsistent naming of old odors, that is, very poor memory performance. By contrast, memory was correct on 98% of the trials for the feedback group when feedback was effective. As predicted, when feedback improved naming, it also improved memory.

Table 5 Percent memory correct for the "old" odors as a function of naming performance during Phases 1 and 2 of testing of Experiment 4

	Memory		
	Incorrect	Correct	Total
Control group			
Naming responses[a]			
Incorrect, incorrect	26	9	35
Incorrect, correct	**30**	**5**	**35**
Correct, incorrect	23	4	27
Correct, correct	1	152	153
Feedback group			
Naming responses[a]			
Incorrect, incorrect	22	8	30
Incorrect, correct	**1**	**55**	**56**
Correct, incorrect	10	9	19
Correct, correct	1	144	145

[a]Incorrect and correct in the table refer to naming responses at Phase 1 and Phase 2, respectively. The bold text highlights the critical comparison.

The results for the new odors were very similar to those found previously. When naming was correct, memory was correct on 90% and 97% of the trials for the control and feedback groups, respectively. When naming was incorrect, memory was correct on 78% and 70% of the trials for the control and feedback groups, respectively. If the naming responses that switched from incorrect to correct are removed for the feedback group, memory was correct on 51% of the inconsistent or incorrect naming trials when responses from old and new odors are combined. This finding replicates the pattern of results observed in the previous experiments and again provides no support for recognition memory when naming is incorrect or inconsistent.

General discussion

As reported by others (Rabin and Cain 1984; Cain and Potts 1996; Larsson and Backman 1997: Lehrner et al. 1999; Lumeng et al. 2005), a clear relationship was observed between odor naming and recognition memory in Experiments 1–4. Odors that were named consistently or correctly were remembered very well, whereas those named inconsistently or incorrectly were remembered very poorly if at all. Across the conditions of Experiments 1–3, memory responses were correct on 2481/2655 trials (93%) if naming was consistent or correct. Memory was correct on 620/1147 trials (54%) when naming was inconsistent or incorrect. This finding provides evidence for a strong link between identification of an odor (as reflected in naming) and episodic memory for that odor. This strong link between semantic knowledge and episodic memory has been proposed previously by investigators working with olfactory (Rabin and Cain 1984; Cain and Potts 1996; Larsson 1997; Bhalla et al. 2000; Larsson et al. 2006), flavor (Lesschaeve and Issanchou 1996; Valentin et al. 2007) and nonolfactory stimuli (Bartlett 1977; Backman 1991; Sternberg et al. 2008). Interestingly, this same relationship was observed in a recent study conducted in our laboratory using notes from different musical instruments as stimuli (Cessna et al. 2010). Consistently identifying the instrument that produced a musical note was an excellent predictor of recognition memory. These findings support the idea that the close relationship between the ability to consistently name and remember stimuli generalizes beyond olfactory stimuli.

It seems likely that several factors contributed to past failures to observe a strong naming–memory relationship. As shown in Experiment 1, consistent naming is important to assess, especially when participants generate their own odor names. Consistency can be assessed only when odors are named at least twice, so past studies providing only one naming opportunity could not generate consistency measures for use in analyses (e.g., Lawless and Cain 1975; Parr et al. 2004). Outside the laboratory, most people learn to name odors with only modest feedback regarding correct responses. This creates an opportunity for people to use nonnormative and idiosyncratic odor labels even when the odors are highly familiar. We propose that consistent naming with a nonnormative label represents just such a circumstance. In addition, many of the artificial odors used in the current studies provide only facsimiles of the odor stimulus associated with a named odor source. This also provides opportunities for nonnormative but consistent labeling. There certainly is evidence that consistent use of nonnormative labels reflects significant odor knowledge (Cain 1979; Sulmont-Rosse et al. 2005).

Using data from individual trials also was important to revealing the strength of the naming–memory relationship. This was essential because individuals vary considerably with respect to their experience with specific odors. Calculating average naming and memory performance for each individual across the odor stimuli glosses over the interaction between experience and odor, blurring the relationship between naming and memory, an observation astutely made by Rabin and Cain (1984). Most past studies have analyzed variability among subjects in their efforts to assess the relationship between odor naming and recognition memory (e.g., Lawless and Cain 1975; Lehrner et al. 1999; Parr et al. 2002, 2004; Moller et al. 2004; Larsson et al. 2006).

Finally, detecting the strength of the naming–memory relationship required separate analysis of the old and new odors. This has not been done routinely in past research. The proposed bias to respond new when naming was inconsistent or incorrect becomes apparent only when old and new stimuli are examined separately.

When a subject cannot name an odor, can it be accurately remembered? In the current studies, little evidence for recognition memory was observed when naming was inconsistent or incorrect. However, past studies have reported evidence for significant recognition memory when naming was poor. A careful comparison of past findings and the current study provides some insights into possible explanations for the differences in outcomes. For example, Lehrner (1993) found that inconsistently labeled odors were none-the-less correctly remembered on 60–70% of the trials in an old/new odor recognition task. In this study, the participants chose between pairs of old and new stimuli for the memory test. This procedure creates the possibility of correctly responding that an odor is old by identifying one of the stimuli as new. A participant using this strategy could give the appearance of correctly remembering an odor even if it was incorrectly named.

Rabin and Cain (1984) reported that incorrectly or inconsistently named odors were remembered at above-chance levels, a finding replicated by Cain and Potts (1996). The signal detection statistic d' was used to measure memory in both studies. Because the proposed bias to respond new when an odor is not identified would have reduced the false alarm rate used to calculate d', the possibility exists that d' was inflated. The extent to which this actually affected the results in these studies is unclear.

Moller et al. (2004) used a set of unfamiliar odors to study recognition memory differences between young and older adults employing both intentional and incidental learning procedures. Evidence for recognition memory was observed for the hard-to-name odors across age groups and learning conditions. However, the ability of study participants to provide veridical names for the odors was not assessed, nor was naming consistency. This raises the possibility that some of the odors could be consistently and correctly named, thereby accounting for the above-chance memory performance.

A recent study by Olsson et al. (2009) also reported above-chance recognition memory for incorrectly named odors. Olsson et al. (2009) did not measure naming consistency, and they counted as correct near-miss naming, whereas a stringent naming criterion was used in the current studies. We have noted that using a lenient versus stringent naming criterion does affect the strength of the relationship between odor naming and memory, with more lenient naming being associated with a weaker relationship. Interestingly, Olsson et al. (2009) found that memory for incorrectly named odors disappeared after a 1-week retention interval, whereas memory for named odors, while diminished, remained well above chance. This finding provides support for the idea that episodic memory for incorrectly named odors is very weak.

In a study of olfactory working memory by Yeshurun et al. (2008), nameable odors were better remembered than hard-to-name odors in a delayed match to sample memory task, but the unnameable odors were correctly remembered on about 80% of the trials. These results support the idea that at least for olfactory working memory, nameability facilitates but is not critical to episodic odor memory. Yeshurun et al. (2008) speculated that observers used olfactory pattern recognition and a more centrally mediated representation of the odor for the nameable odors but relied more on lower level pattern recognition for unnameable odors. It is noteworthy that the retention interval in the study of Yeshurun et al. (2008) was 12 s in contrast to at least 10 m in the current studies. Odor knowledge (as reflected in nameability) may be increasingly important to accurate memory as the retention period increases. In addition, it is also noteworthy that Yeshurun et al. (2008) had participants rate the nameability of the odors not actually name them as was done in the current studies.

Notwithstanding differences in naming procedures and analytic approaches, as noted above, the published literature provides multiple examples of recognition memory for hard-to-name odors (see also Cleary et al. 2010). The experimental protocols used in the current studies may have tilted the results toward a reliance on odor names. Unlike most past studies of odor naming and memory, odor name alternatives were provided in most of the conditions used in the present studies. The provision of odor names may have encouraged participants to rely more on verbal representations of the odors during testing and thereby produced a stronger relationship between naming and memory than observed in some previous studies. However, it is noteworthy that odor memory remained poor for inconsistently named odors even under conditions where no odor names were provided. The choice of stimuli also may have influenced the results. All the odors used in the current experiments were chosen to be easily named, which may have encouraged participants to adopt strategies that rely heavily on verbal processes.

The results of Experiments 1–4 support the idea that effective odor naming and episodic memory both relied on matching current olfactory input to an acquired, multifaceted representation of an odor. This representation links patterns of olfactory input to associations with objects, environmental context, and lexical features. Matching the current input to the stored representation enables the meaningful interpretation of the olfactory experience so that it can be named, described in detail, and remembered in the future. When the odor representation is not identified, the meaning of the olfactory experience is muddled, descriptions are vague and unreliable, and the context in which the odor was encountered is difficult to remember. From this perspective, verbal labels support better recognition memory indirectly by improving perception of odor objects, not by improved memory processing per se. We argue that a similar explanation accounts for improved odor discrimination in the presence of verbal labels (De Wijk and Cain 1994). As with naming and recognition memory, discrimination improves as a result of improved identification of the odor object.

Is it possible that only the odor name and not olfactory sensation is being remembered during retrieval? This is possible and would be consistent with a multidimensional view of odor memory. The best test of this view is provided by the condition where odor names are self-generated. Suppose a participant labels an odor "orange" at encoding and now encounters an orange odorant at retrieval. The participant now needs to match the olfactory pattern produced by the stimulus with a stored representation that allows the orange sensory pattern to be identified and tied to the word orange. Once this is done, all the participants need to remember is that he or she responded orange during the encoding phase in order to respond old for the test. Notice, however, that the correct response required much more than simply remembering the verbal response orange. It was critical that the semantic information be tied to the stored olfactory pattern. Generating the correct response depended on this multidimensional representation. This is not to suggest that all olfactory recognition memory relies on verbal coding. Rather, the point is that remembering verbal labels could have played an important role in episodic memory performance in the current studies.

The idea that odor memory is multidimensional stands in contrast to the proposition that odors are encoded and stored as unitary perceptual events (Engen and Ross 1973). Interestingly, one of the observations used to support this view, the flat odor recognition memory forgetting curve, was not observed in a recent study by Olsson et al. (2009). In fact, these investigators observed comparable forgetting rates for nameable odors and words and complete forgetting of incorrectly named odors. Dual-coding theory (Paivio 1991) provides another alternative to the multidimensional view of odor memory. This theory proposes that there are separate memory systems for the olfactory pattern and odor names with a learned association between the 2 memory types. The strong relationship between accurate or consistent naming and episodic memory performance is consistent with dual-coding theory, but the poor memory associated with incorrect or inconsistent naming is not. There should be some evidence for remembering inconsistently named odors because the olfactory memory for some of these odors should be strong enough to support episodic memory even if semantic odor memory and the odor name association is poor. However, no evidence for episodic memory was found with inconsistently named odors. It might be argued, based on the below chance memory performance observed for inconsistently named old odors, that providing the wrong name for an odor interferes with later retrieval of an episodic memory for that odor, in support of dual-coding theory. However, inconsistently named odors that were named incorrectly at either encoding or retrieval showed the same memory pattern. The interference hypothesis would have predicted that correct naming at encoding should have produced less interference (and thus better memory) than incorrect naming at encoding.

The studies described in this report were initially motivated by a desire to develop a rapid, simple test for semantic and episodic odor memory that could be used clinically as an early screen for neurodegenerative disorders. At the very least, the findings suggest that a patient's ability to consistently identify odors should be taken into account when assessing performance on odor recognition memory tests. It certainly would be interesting to investigate olfactory recognition memory in patients with neurodegenerative diseases after correcting for naming consistency. A study by Murphy et al. (1997) came close to doing this. These investigators examined odor naming and memory in young and older adults, correcting odor recall performance for odor identification. They concluded that odor recall was dependent on identification. Although odor recognition memory was tested, the relationship between identification and recognition memory was not assessed. A future study of odor-naming consistency and recognition memory in people with mild cognitive impairment could provide insight into the connection between olfaction and early onset of dementia. In addition, the results could illuminate further the nature of semantic and episodic odor memory processes.

Supplementary material

Supplementary material can be found at http://www.chemse.oxfordjournals.org/.

Acknowledgements

The authors thank Dr Lloyd Hastings for use of the Osmic Enterprises OLFACT system in the experiments and for technical support of the studies. We also thank Jason Bailie, Steve Howe, and Jim Deddens for assistance with collecting and analyzing the data and Richard J. Stevenson, Trevor Cessna, and 3 anonymous reviewers for their insightful comments on an earlier draft of the paper.

References

Backman L. 1991. Recognition memory across the adult life span; the role of prior knowledge. Mem Cognit. 19:63–71.

Bailie JM, Rybalsky KA, Hastings L, Knauf B, Shollenbarger S, Mannea E, Brearton MS, Gesteland RC, Frank RA. 2007. Odor memory: the effect of verbal labeling. Chem Senses. 32(6):A117 (online abstract).

Bartlett JC. 1977. Remembering environmental sounds: the role of verbalization at input. Mem Cognit. 5:404–414.

Bhalla M, Marcus KM, Cornwell JM. 2000. Odor recognition and identification: effects of labels over time. Psychol Rep. 86:565–574.

Boesveldt S, Verbaan D, Knol DL, Visser M, van Rooden SM, van Hilten JJ, Berendse HW. 2008. A comparative study of odor identification and odor discrimination deficits in Parkinson's disease. Mov Disord. 23:1984–1990.

Brearton MS, Balasubramaniam N, Bailie JM, Rybalsky KA, Mannea EJ, Wallace B, Hastings L, Frank RA. 2008. Effects of response alternatives on odor naming and recall. Chem Senses. 33(8):S64 (online abstract).

Brearton MS, Frank RA. 2010. The odor naming power test: evaluating the relationship of odor naming ability and recognition memory performance. Chem Senses. 35(7):A119 (online abstract).

Butler AC, Roediger HL. 2008. Feedback enhances the positive effects and reduces the negative effects of multiple-choice testing. Mem Cognit. 36:604–616.

Cain WS. 1979. To know with the nose; keys to odor identification. Science. 203:467–470.

Cain WS. 1982. Odor identification by males and females: predictions vs performance. Chem Senses. 7:129–142.

Cain WS, de Wijk R, Lulejian C, Schiet F, See LC. 1998. Odor identification: perceptual and semantic dimensions. Chem Senses. 23:309–326.

Cain WS, Krause RJ. 1979. Olfactory testing: rules for odor identification. Neurol Res. 1:1–9.

Cain WS, Potts BC. 1996. Switch and bait: probing the discriminative basis of odor identification via recognition memory. Chem Senses. 21:35–44.

Cessna T, Brearton MS, VanDeGrift KM, Rybalsky K, Frank RA. 2010. Characterizing the relationship between naming and recognition memory for odors and sounds. Chem Senses. 35(7):A48 (online abstract).

Cleary AM, Konkel KE, Moni JS, McCabe DP. 2010. Odor recognition without identification. Mem Cognit. 38:452–460.

De Wijk RA, Cain WS. 1994. Odor quality: discrimination versus free and cued identification. Percept Psychophys. 56:12–18.

Desor JA, Beauchamp GK. 1974. The human capacity to transmit olfactory information. Percept Psychophys. 16:551–556.

Djordjevic J, Jones-Gotman M, De Sousa K, Chertkow H. 2008. Olfaction in patients with mild cognitive impairment and Alzheimer's disease. Neurobiol Aging. 29:693–706.

Doty RL, Shaman P, Dann M. 1984. Development of the University of Pennsylvania Smell Identification Test: a standardized microencapsulated test of olfactory function. Physiol Behav. 32:489–502.

Engen T. 1987. Remembering odors and their names. Am Sci. 75:497–503.

Engen T, Ross BM. 1973. Long-term memory of odors with and without verbal descriptions. J Exp Psychol. 100:221–227.

Eskenazi B, Cain WS, Novelly RA, Friend KB. 1983. Olfactory functioning in temporal lobectomy patients. Neuropsychologia. 21:365–374.

Haladyna TM, Downing SM, Rodriguez MC. 2002. A review of multiple-choice item-writing guidelines for classroom assessment. Appl Meas Edu. 15:309–333.

Hastings L, Wilson T. 2004. Test of olfaction based upon a MEMS-microvalve olfactometer. Paper Presented at the Association for Chemoreception Sciences. Sarasota (FL).

Horning SM, Bailie JM, Rybalsky KA, Frank RA. 2006. Odor memory and labeling in adults and children. Poster Presented at Annual Meeting of the Association for Chemoreception Sciences. Sarasota (FL).

Hummel T, Konnerth CG, Rosenheim K, Kobal G. 2001. Screening of olfactory function with a four-minute odor identification test: reliability, normative data, and investigations in patients with olfactory loss. Ann Otol Rhinol Laryngol. 110:976–981.

Jehl C, Royet JP, Holley A. 1997. Role of verbal encoding in short- and long-term odor recognition. Percept Psychophys. 59:100–110.

Jonsson FU, Olsson MJ. 2003. Olfactory metacognition. Chem Senses. 28:651–658.

Jonsson FU, Tchekhova A, Lonner P, Olsson MJ. 2005. A metamemory perspective on odor naming and identification. Chem Senses. 30:353–365.

Larsson M. 1997. Semantic factors in episodic recognition of common odors in early and late adulthood: a review. Chem Senses. 22:623–633.

Larsson M, Backman L. 1997. Age-related differences in episodic odour recognition: the role of access to specific odour names. Memory. 5:361–378.

Larsson M, Oberg C, Backman L. 2006. Recollective experience in odor recognition: influences of adult age and familiarity. Psychol Res. 70: 68–75.

Lawless H, Cain WS. 1975. Recognition memory for odors. Chem Senses. 1:331–337.

Lehrner JP. 1993. Gender differences in long-term odor recognition memory: verbal versus sensory influences and the consistency of label use. Chem Senses. 18:17–26.

Lehrner JP, Gluck J, Laska M. 1999. Odor identification, consistency of label use, olfactory threshold and their relationships to odor memory over the human lifespan. Chem Senses. 24:337–346.

Lesschaeve I, Issanchou S. 1996. Effects of panel experience of olfactory memory performance; influence of stimulus familiarity and labeling ability of subjects. Chem Senses. 21:699–709.

Lumeng JC, Zuckerman MD, Cardinal T, Kaciroti N. 2005. The association between flavor labeling and flavor recall ability in children. Chem Senses. 30:565–574.

Lyman BJ, McDaniel MA. 1986. Effects of encoding strategy on long-term memory for odours. J Exp Psychol Hum Learn Mem. 38: 753–765.

Lyman BJ, McDaniel MA. 1990. Memory for odors and odor names: modalities of imagination and imagery. J Exp Psychol Learn Mem Cogn. 16:656–664.

Mannea EJ, Bailie JM, Rybalsky KA, Hastings L, Brearton MS, Knauf B, Frank RA. 2008. Decline in odor memory and odor identification performance across the adult lifespan. Chem Senses. 33(8):S63 (online abstract).

Moller P, Wulff C, Koster EP. 2004. Do age differences in odour memory depend on differences in verbal memory? Learn Mem. 15: 915–917.

Murphy C, Nordin S, Acosta L. 1997. Odor learning, recall and recognition memory in young and elderly adults. Neuropsychology. 11:126–137.

Murphy C, Nordin S, Jinich S. 1999. Very early decline in recognition memory for odors in Alzheimer's disease. Aging Neuropsychol Cogn. 6:229–240.

Olsson MJ, Lundgren EB, Soares SC, Johansson MJ. 2009. Odor memory performance and memory awareness: a comparison to word memory across orienting tasks and retention intervals. Chemosens Percept. 2:161–171.

Paivio A. 1991. Dual coding theory: retrospective and current status. Can J Psychol. 45:255–287.

Parr WV, Heatherbell D, White KG. 2002. Demystifying wine expertise: olfactory threshold, perceptual skill and semantic memory in expert and novice wine judges. Chem Senses. 27:747–755.

Parr WV, White KG, Heatherbell D. 2004. Exploring the nature of wine expertise: what underlies wine experts' olfactory recognition memory advantage? Food Qual Prefer. 15:411–420.

Ponsen MM, Stoffers D, Booij J, van Eck-Smit BLF, Wolters EC, Berendse HW. 2004. Idiopathic hyposmia as a preclinical sign of Parkinson's disease. Ann Neurol. 56:173–181.

Rabin MD, Cain WS. 1984. Odor recognition: familiarity, identifiability, and encoding consistency. J Exp Psychol Learn Mem Cogn. 10:316–325.

Roediger HL, Marsh EJ. 2005. The positive and negative consequences of multiple-choice testing. J Exp Psychol Learn Mem Cogn. 31:1155–1159.

Ross CM, Petrovich H, Abbott RD, Tanner CM, Popper J, Masaki K, Launer L, White LR. 2008. Association of olfactory dysfunction with risk for future Parkinson's disease. Ann Neurol. 63:167–173.

Schemper T, Voss S, Cain WS. 1981. Odor identification in young and elderly persons: sensory and cognitive limitations. J Gerontol. 36:446–452.

Sternberg G, Hellman J, Johansson M. 2008. The memorability of names and the divergent effects of prior experience. Eur J Cogn Psychol. 20:312–345.

Stevenson RJ, Wilson DA. 2007. Odour perception: an object-recognition approach. Perception. 36:1821–1833.

Sulmont-Rosse C, Issanchou S, Koster EP. 2005. Odor naming methodology: correct identification with multiple-choice versus repeatable identification in a free task. Chem Senses. 30:23–27.

Valentin D, Chollet S, Beal S, Patris B. 2007. Expertise and memory for beers and beer olfactory compounds. Food Qual Prefer. 18:776–785.

Wilson RS, Arnold SE, Schneider JA, Tang Y, Bennett DA. 2007. The relationship between cerebral Alzheimer's disease pathology and odour identification in old age. J Neurol Neurosurg Psychiatr. 78:30–35.

Yeshurun Y, Dudai Y, Sobel N. 2008. Working memory across the nostrils. Behav Neurosci. 122:1031–1037.

Zucco GM. 2003. Anomalies in cognition: olfactory memory. Eur Psychol. 8:77–86.