Implicit and explicit memory for odors: Hemispheric differences

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In two experiments, implicit and explicit tests were used to investigate the lateralization of odor memory. Odors were at all times presented monorhinically. At test, odors were presented to either the ipsi- or the contralateral side of the nostril used for inspection. In Experiment 1, participants were first primed to a set of odors. At test, response latencies for odor identification were measured. The results were that priming odors tested via the left but not the right nostril were identified faster than control odors. In Experiment 2, a similar design probed episodic recognition memory. Memory performance did not differ between the left and right nostrils, but the measures of response latency favored the right side. The study demonstrates that it is possible to tap differences in memory performance between the cerebral hemispheres through monorhinic presentation of odors in healthy persons, and that these differences depend on the test nostril rather than the inspection nostril.

Studies of odor memory have dealt principally with explicit forms of memory even though implicit forms may provide a common means to learn about odors (Cain, de Wijk, Luleijan, Schiet, & See, 1998; de Wijk, Schab, & Cain, 1995; Herz & Engen, 1996). In everyday life, odors often lie in a contextual relationship to other events, such as a rain shower, spring thaw, dinner under way, or soiling of a diaper. Attention often focuses on how we should behave toward the events rather than on the identity or names of the odors per se (de Wijk & Cain, 1994; Engen, 1987). As Engen (1991) noted: "Olfaction is a primitive survival system serving the function of quickly categorizing experiences with the chemistry of the environment without reasoning about them . . . . Odors are named by function, what one does with them and in what context . . . . Other means of encoding than language must be involved" (pp. 83-85). Not surprisingly, people show much poorer naming of objects via smell than via sight. Indeed, a person who identified common objects via sight as badly as via odor might seem demented (Cain et al., 1995). Nevertheless, people do negotiate the world of odors successfully. They approach the good and avoid the bad. They eat the edible and wash the sweaty-smelling gym clothes. Both explicit and implicit processes apparently forge the rather complex relationship between odors and their sources, and the person.

Studies of priming (e.g., Graf & Schacter, 1985) of odors have given a sketchy view of when it occurs. Schab and Crowder (1995), for example, found no priming for thresholds. That is, they found no better sensitivity from brief previous exposure, but claimed priming for identification (cf. Olsson, Faxbrink, & Jönsson, 2002). Olsson et al. found no priming in judgments of odor quality, but Koenig, Bourron, and Royet (2000) and Olsson and Fridén (2001) found facilitation in judgments of edibility. In particular, participants judged edibility faster for odors previously examined than for novel odors.

In the vein of Schab and Crowder (1995), the present study concerned priming of identification. When people try to name odors, they do so slowly, taking more than 4 sec on average when correct and more than 9 sec when not (Wise & Cain, 2002). Simple reaction time to odor equals less than a second, so that 3 or more of the 4 sec on the successful trial apparently entail activation and articulation of the name (see Johnson, Paivio, & Clark, 1996). If unburdened by instruction of the need to express the name, a person might engage in little or no verbal processing when seeking realization of identity. We sought in this manner to establish whether prior exposure to odors would prime realization.

Schacter (1994) and various others have argued that implicit memory, and priming in particular, manifests the operation of a different neurocognitive system than does

explicit memory. The evidence comes, for instance, from finding different patterns of outcome for more or less parallel explicit and implicit tasks. The former asks for recall or recognition of previously presented information and the latter does not, but assesses how the previously presented information reflects itself otherwise (e.g., Hayman & Tulving, 1989; Jacoby, 1991; La Voie & Light, 1994; Ostergaard, 1993). In some cases, the comparison of explicit and implicit processing has entailed a contrast between the right and left hemispheres. For example, Marsolek, Kosslyn, and Squire (1992) found that form-specific priming of graphic stimuli revealed itself in the right hemisphere more than the left, whereas the explicit task of cued recall revealed no advantage for the right (see Ochsner & Kosslyn, 1999, for other examples).

Studies of healthy persons and of patients with brain lesions have indicated that the right hemisphere plays a generally dominant role in olfactory processing, particularly for discrimination of odor quality (e.g., Martinez et al., 1993; Zatorre & Jones-Gotman, 1990) and episodic recognition (e.g., Jones-Gotman & Zatorre, 1993). The functional asymmetry undoubtedly has more facets than studied so far (Brand, Millot, & Henquell, 2001; Doty, Bromley, Moberg, & Hummel, 1997). Nevertheless, findings of greater neural activation in the right hemisphere, especially in orbitofrontal cortex, during discrimination of quality, judgments of familiarity, and episodic recognition are consistent with the functional asymmetry (e.g., Dade, Jones-Gotman, Zatorre, & Evans, 1998; Kobal & Kettenmann, 2000; Royet et al., 2001; Savic & Gulyas, 2000; Savic, Gulyas, Larsson, & Roland, 2000; but see Royet et al., 2000).

Semantic memory for odors seems not to follow the rule of right dominance. Some investigators have and some have not found superior odor identification via the left nostril, but none has found superior identification via the right nostril (Broman, Olsson, & Nordin, 2001; Herz, McCall, & Cahill, 1999; Homewood & Stevenson, 2001). The use of single-nostril (monorhinic) stimulation in these cases derives from the expectation that preferential unilateral processing will occur. Projections from the olfactory periphery do remain predominantly ipsilateral (Brand et al., 2001). Although imaging has shown that unilateral stimulation leads to bilateral cortical activation (Savic & Gulyas, 2000), the activation is not necessarily identical (Hummel et al., 1995; Savic & Gulyas, 2000; Tonoike et al., 1998).

Monorhinic stimulation has served particularly usefully in studies to explore the side of olfactory deficit in patients with unilateral brain lesions (e.g., Eskenazi, Cain, Novelly, & Mattson, 1986; Potter & Butters, 1980). It has served less effectively in studies of normals, perhaps because of failure to focus on the variable of time. For normal persons, unilateral stimulation bestows the advantage of first access on the ipsilateral side, rather than total unilateral access (see Kosslyn et al., 1989). Hence, to use the technique effectively, one should presumably study time rather than accuracy.

EXPERIMENT 1
Repetition Priming

This experiment followed a lead from studies of visual priming. Cave and Squire (1992), for example, asked amnesic patients and healthy participants to name pictures either once or twice at two retention intervals. Reduction in latency to name those shown previously against new pictures indicated repetition priming. Whereas amnesic patients exhibited impaired explicit recognition of prior occurrence, they exhibited fully intact priming. Mitchell and Brown (1988) observed a similar reduction in latency for repeated naming of pictures. Importantly, the reduction occurred irrespective of whether participants consciously recognized the particular pictures from the previous inspection. Hence, these procedures evidenced priming independent of explicit memory.

To test for priming in the present instance, participants attempted, in a timed task, to identify odors previously presented for inspection, but not to name them vocally. This approach seems to confront olfaction more or less on its own terms, because activation and vocalization of a name often takes many seconds. Identification and name activation seem to represent different processes even outside olfactory processing (Johnson et al., 1996; McCauley, Parmalee, Sperber, & Carr, 1980), though olfaction may provide the starkest instance of the phenomenon. So, a task that minimized the need to activate an explicit label seemed likely to reduce lexical contamination of the response over the relevant duration and, we hoped, to uncover a olfactory-relevant outcome. We hypothesized that priming would occur more prominently on the left than on the right in this case of monorhinic stimulation. Latency was the outcome of interest.

Method

Participants. Thirty-two females and 32 males, ranging in age from 18 to 51 years ($M = 23.2$, $SD = 5.9$), participated. The participants were primarily students (paid $8) and staff (uncompensated) from the university community in San Diego. All professed right-handedness, a matter confirmed by responses to 9 of the 10 items on the Edinburgh Inventory for Handedness (Oldfield, 1971), completed at the beginning of a session. Maximally right-handed persons would score 9, whereas maximally left-handed would score 0. The participants scored an average of 8.91 ($SD = 0.29$, range = 8–9). In another questionnaire concerning their health status and medical history, participants attested to good health, absence of nasal obstruction, and no use of drugs considered relevant to olfactory functioning.

Stimuli. Two sets of six particularly identifiable odors from 48 items used in an earlier study served as stimuli (Olsson & Cain, 1995). Set A contained mothballs, peppermint, coffee, fruit gum, orange essence, and cinnamon. Set B contained cigar butts, Vicks VapoRub, chocolate, baby powder, lemon peel, and cloves. Three to five other odors were used to accustom participants to the timing procedure. Odors were presented from 180-ml opaque plastic jars with screw lids. Odorless packing around the source precluded visual identification. Participants were instructed to close their eyes when the experimenter presented a stimulus.

Procedure. The dependent variable was latency to press a response key to indicate implicit identification of an odor. A sound

prompted the participant to begin the sniff; latency to the pressing of the response key to indicate that he/she had identified the odor was measured. Odors were smelled only monorhinically. Half the participants were tested for priming effects in the left nostril and half in the right. Furthermore, in the test for priming, half the participants received the odors on the same side as in the inspection phase (ipsilateral testing) and half on the opposite side (contralateral testing). To indicate realization of identity, participants pressed the key with the thumb of the hand designated by the experimenter. Half the participants used the hand ipsilateral to the nostril used in the test for priming and half used the hand contralateral to that nostril. Consequently, half the participants using either nostril pressed the button with the right hand and half with the left hand.

The session consisted of three phases: inspection, test for priming, and a naming test. During inspection, half the participants smelled the odors from Set A and half from Set B. Each participant received the six odors of a set in a unique, randomly determined sequence. The participants, who held the stimuli to their own noses, could sniff the odors for as long as they wished in inspection, typically a few seconds. An odor was always sniffed via one nostril with the other nostril blocked with one thumb until the participant responded to the question: "When was the last time you smelled this odor?" The range of responses made available to the participant on a printed sheet included the following: (1) within the last day, (2) between 1 day and 1 week ago, (3) between 1 week and 1 month ago, (4) between 1 month and 1 year ago, (5) more than 1 year ago, and (6) never. The participants were instructed to use just the category numbers and otherwise not to speak.

Before the test for priming, participants practiced the task with an empty jar and then with three to five practice odors. In the actual test, approximately 5 min after inspection, the participants were presented with 12 test odors, those in both Sets A and B in a uniquely randomized order. Hence, 6 odors had previously appeared and 6 had not. For this task the participant leaned over to the odor jar placed on the table in front of him/her and gently exhaled as the nose approached the jar. When the nose reached about an inch from the jar, the participant stopped the exhalation and then began to inhale on signal. The participant then took one sniff of optional length and leaned back from the jar after the sniff was completed. Participants were instructed to press the response key as soon as they realized the identity of an item. The participants did not need to name the odor at that time.

To illustrate the task to the participant, the experimenter gave an example of the odor of ketchup. He noted that one might realize the odor to be ketchup before its actual name came to mind. This response mode seemed to require less lexical processing than if the name was required. However, it was pointed out that a "feeling of knowing" did not qualify, because it is a state of mind that does not reliably predict performance on a cued odor identification test (Cain et al., 1998). By the instructions, the participants had to feel confident of having identified the odor.

The third phase entailed presentation of the same 12 odors in the same order as in the second phase, but without timing the response. Again participants sniffed the odors via only one nostril, but this time verbalized a name for each odor.

Results

At the test for priming, the participants indicated identification on 93% of trials for odors in their respective priming sets and 89% of trials for their respective control odors. In the subsequent naming test, scores equaled 82% and 78%, respectively, by a strict criterion, and 88% and 85%, respectively, by a less strict criterion. None of these differences between sets achieved significance by chi-square test. Accordingly, the task of inspection generated no greater ability to name the odors.

The response latencies in the test for priming generated positively skewed distributions that became more symmetric when converted to logarithms (see also Olsson & Fridén, 2001). An analysis of variance (ANOVA) on the logarithms with four two-level factors included one within-subjects factor (priming vs. control odors) and three between-subjects factors: study nostril (ipsi- or contralateral nostril between study and test), nostril tested, and sex. Because choice between Sets A and B as primers and hand used to press the response key proved inconsequential, they did not appear in the results of the ANOVA.

On average, participants identified the priming odors 9% faster than control odors. The priming odors yielded an average latency of 0.280 log sec (1.905 sec), whereas the control odors yielded an average latency of 0.320 log sec (2.089 sec) $[F(1,56) = 9.578, p = .003]$. The factors of nostril tested in identification, nostril used for inspection, and sex yielded no significant differences.

One significant two-way interaction emerged—namely, experimental condition (priming vs. control odors) $\times$ nostril $[F(1,56) = 5.004, p = .03$; Figure 1]. Prior inspection exerted its effect on speed of identification via the left nostril $[t(31) = 0.721, p = .008]$ but not the right $[t(31) = 0.540$, n.s.; Figure 1]. Latency for priming odors presented to the left side equaled 0.249 log sec (1.774 sec), and latency for the control odors equaled 0.318 log sec (2.078 sec), a gain of 15%. The corresponding values for the right side equaled 0.311 log sec (2.046 sec) and 0.322 log sec (2.099 sec), respectively—just 3%.

Which odors exhibited the priming effects? Odors that participants found more difficult to identify had a tendency to show larger priming effects. The product–moment correlation coefficient over the 12 odors between proportion of correct explicit identification (relaxed criterion) and primability (latency [log sec] for the odor when it appeared as a control stimulus minus latency [log sec] for
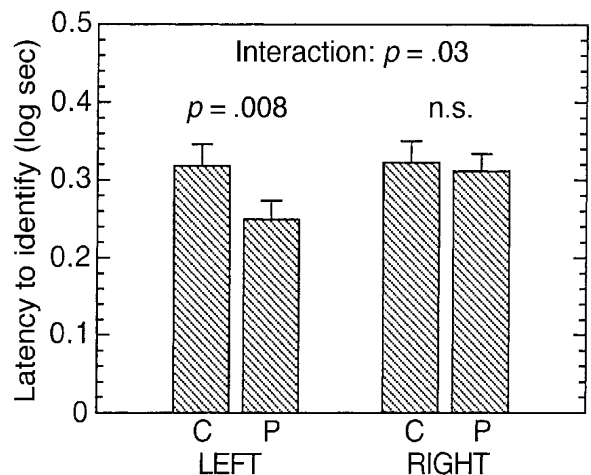
Figure 1. Mean latency (log seconds) to implicit identification tested via the left and right nostrils. C, control odors; P, priming odors.

when it appeared after priming) equaled $r(10) = -.47$ (n.s.). Likewise, the correlation between identification latency (log sec) in the control condition and primability yielded $r(10) = -.41$ (n.s.).

Discussion

Identification as measured in the present study yielded an average latency of about 2 sec, less than half that taken for verbal identification, with an overall gain from repetition priming of around 9% and a gain for odors tested on the left side of around 15%. The insignificant gain on the right side equaled 3%. Compared with similar experiments investigating effects of visual priming, these data imply a substantial facilitatory effect. For example, Mitchell and Brown (1988) found object naming for pictures to occur at about 800 to 900 msec, with a gain from repetition priming of 8% to 9%. Another picture-naming study (Carroll, Byrne, & Kirsner, 1985) that required naming only at test yielded approximately the same naming latencies, but a gain from previous exposure of only 3% to 4%.

EXPERIMENT 2
Episodic Recognition

The second experiment explored whether episodic recognition memory would show the asymmetry seen with priming. Findings of Bromley and Doty (1995) that monorhinic inspection and testing yielded no difference in accuracy of episodic memory between right and left stimulation led us to expect no such difference either. In the present context, however, the question of principal interest concerned speed of recognition rather than accuracy. A difference in pattern between right and left sides could indicate operation of different processes between the tasks.

Method

This experiment used the same stimuli and followed the same basic design as the priming experiment with only minor differences, pointed out below.

Participants. Thirty-two females and 32 males, ranging in age from 18 to 30 years ($M = 22.8$, $SD = 6.13$), participated. The participants came from the same pool and received the same compensation as those in the previous experiment, though none had participated in it. Recruited as right-handers, their handedness scores averaged 8.67 ($SD = 0.62$, range = 6.5–9).

Stimuli. The present experiment used the 12 test stimuli (6 in Set A and 6 in Set B) from the first experiment. The present experiment included 6 practice stimuli for participants to become acquainted with the timing procedure. These practice odors were wintergreen, nutmeg, tea, Ivory soap, peanut butter, and black pepper.

Procedure. Each session had two phases, similar to the first two phases of the first experiment. During an inspection phase, participants smelled the six odors in either Set A or Set B and indicated when they had last smelled that odor. The participants were not told that a test for recognition would follow. Between inspection and a test phase, the participants answered the nine questions in the Edinburgh Inventory for Handedness, which served as a distraction task. In the test phase, approximately 5 min after inspection, participants smelled the 6 practice odors, 6 odors from the inspection phase (targets), and 6 new odors (lures), and responded in each instance whether or not they had smelled the odor during the inspec-

tion phase. As soon as they knew the answer, they pressed a response key and immediately responded "yes" or "no." They also gave a confidence rating for the correctness of the response. The response alternatives were (1) *not confident*; (2) *somewhat confident*; (3) *very confident*.

Results

Correctness and confidence. An ANOVA (study nostril × nostril tested × sex) performed on the nonparametric measure A' (Donaldson, 1996; Pollack & Norman, 1964) indicated no reliable difference between memory as tested for the left versus the right nostril (mean A' equaled 0.85 and 0.86, respectively) [$F(1,56)$ < 1]. All other main effects and interactions also failed to achieve statistical significance.

Aggregate ROC curves constructed across participants from the five decision criteria derived from the six combinations of recognition responses (yes/no) and confidence ratings (*not confident*, *somewhat confident*, and *very confident*) (Macmillan & Creelman, 1991) showed that performance via the left nostril essentially equaled that via the right (Figure 2). The curves also indicated, not surprisingly, comparable decision strategies between the nostrils.

Latency of recognition. An ANOVA (target/lure × study nostril × nostril tested × sex) performed on latencies (log seconds) indicated 10% shorter latency to target odors (0.263 log sec; 1.832 sec) than to lures (0.310 log sec; 2.042 sec) [$F(1,56) = 12.061, p = .001$; Figure 3]. Odors tested on the right side showed shorter latency than those tested on the left [$F(1,56) = 4.039, p < .05$; Figure 3]. Nevertheless, the interaction between side tested and condition (target vs. lure) failed to reach significance [$F(1,56) = 0.739$, n.s.].

GENERAL DISCUSSION

To summarize: In a test of priming (Experiment 1), participants first sniffed various odors monorhinically and in-
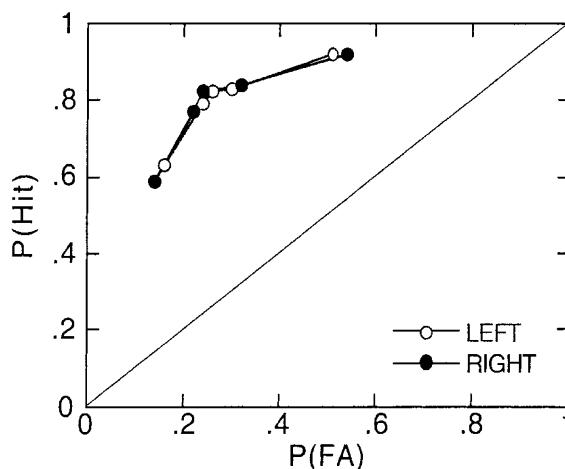

Figure 2. ROC curves for odor recognition memory constructed from five decision criteria. Separate curves are shown for memory tested via the left and right nostrils. FA, false alarms.
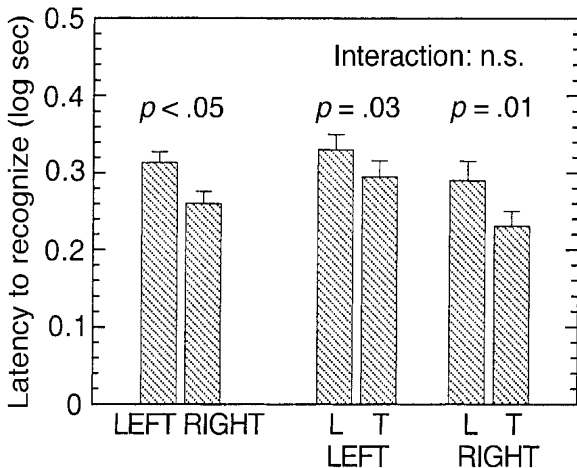
Figure 3. Mean latency (log seconds) to recognize previous presentation tested via the left and right nostrils. L, lures; T, targets.

dicated, as an orienting task, when they had last smelled them. When asked to sniff odors 5 min later, the participants realized identity for the priming odors faster than for control odors, though only via the left nostril. As judged from naming of both priming and control odors afterward, participants had not identified the primed odors significantly better, just faster. In an explicit test (Experiment 2), participants first sniffed various odors monorhinically and, as in Experiment 1, indicated when they had last smelled them. When asked to recognize odors 5 min later, the participants responded faster when tested via the right nostril. Study nostril did not matter in either case.

Ipsi- Versus Contralateral Testing

Repetition priming has been argued to exhibit "hyperspecificity" (e.g., Hayman & Tulving, 1989). That is, small changes in the stimulus characteristics between study and test may diminish the priming effect. Such changes impair explicit memory tests to a lesser degree. Therefore, effects of changing nostrils between inspection and test could, hypothetically, have proven consequential to the priming effect, but not to explicit memory in the present study. The fact that an effect of inspection side was not observed may be explained by the general inability of humans to localize the nostril being stimulated by an odor (Kobal, Van Toller, & Hummel, 1989). In line with the present study, Cronin-Golomb, Gabrieli, and Keane (1996) failed to show any difference between ipsi- and contralateral testing for visual word-stem completion priming.

Episodic Recognition

Lyman and McDaniel (1990) made a strong case for dual perceptual and semantic encoding in memory for odors. Semantic encoding of odors, assessed by the quality of names assigned to stimuli, accounts for a considerable amount of variance in performance in recognition memory (Larsson, 1997; Murphy, Cain, Gilmore, &

Skinner, 1991; Rabin & Cain, 1984). Even though a simple recognition task would seem to require no semantic involvement, it apparently does.

Verbal semantic retrieval, and presumably encoding, of odors seems to engage principally the left hemisphere, whereas nonverbal retrieval of semantic information engages at least the right and perhaps both. Split-brain patients studied monorhinically showed good ability to name odors via the left hemisphere, but poor or absent ability via the right hemisphere (Gordon & Sperry, 1969). These patients could, however, mediate visual and tactual identification of odors; for example, matching the feel or sight of a lemon to lemon odor, via the right or the left. Verbal processing may of course have mediated or facilitated the intersensory ability on the left. The outcome suggests in any case a distribution of semantic knowledge for odors across the hemispheres, but with some asymmetry in type of encoding.

As noted above, the right hemisphere seems to process information regarding odor quality and prior occurrence better than the left. In neurobiological studies, Jones-Gotman, Zatorre, Evans, and Meyer (1993) noted increased cerebral blood flow to the hippocampus and the parahippocampal gyrus on the right side during episodic recognition of odors. For the same task, other studies indicated activation in the right orbitofrontal cortex (Dade et al., 1998; Royet et al., 2001; Savic et al., 2000). It is tempting to speculate that in the present study the right side might have initiated processing of recognition for odors sniffed by both the right and left nostrils, which could account for the shorter latency on the right.

To the best of our knowledge, no previous studies of recognition memory for odors have measured latency to respond. Inevitably, such measurements invite participants to respond more quickly than they might otherwise. The impulse to respond quickly might bias processing toward the dominant right side and diminish the role of verbal/semantic factors, which in any case probably emerge more slowly than perceptual factors. An investigation of the role of speed in the association between semantic encoding and recognition might prove useful to delineate the time course of decisions in explicit memory for odors.

Repetition Priming

Why did the temporal precedence of monorhinic presentation accelerate identification on the left side and not the right if information about identity exists on both sides? There exist various tasks where readout seems more the province of the left hemisphere than the right (see Ochsner & Kosslyn, 1999, for a review). Despite our statements about the availability of semantic information on the right side, tasks that have shown its availability actually entailed a variety of recognition that lies between recognition of prior occurrence and free identification in difficulty. When aided with choices, participants recognize the identity of odors far better than when asked to name the odors freely. In the experiments that

entailed intersensory matching in split-brain patients, the participants had a limited set of objects from which to choose, which essentially made the task multiple choice. Perhaps the semantic information on the right makes itself available only when an odor itself, or matching intersensory cues, occurs. In free identification, the left side may need to bear the burden, which could account for why the left side benefited differentially from the priming.

Could explicit processing have mediated the repetition shown here? The argument could be made that the observed reduction of latencies in Experiment 1, interpreted here as repetition priming, was critically mediated by explicit memory in some way. Although this possibility cannot be excluded, similar procedures to probe priming have been validated against performance in amnesic patients (Cave & Squire, 1992) and against measures of explicit memory (Mitchell & Brown, 1988), excluding the possibility of explicit mediation in these studies. A nonimplicit interpretation of the reduction of identification latencies for repeated odors in Experiment 1 can start with the fact that participants attempted to identify priming odors twice, whereas they attempted to identify control odors only once—and even relatively common odors are generally difficult to identify. Multiple attempts to access the identity of the odors are therefore likely to increase the average identification rate for priming odors. However, as shown in the Results section of Experiment 1, identification rates did not increase significantly for priming odors relative to control odors.

It has been suggested that episodic recognition can intervene in implicit tests of memory (e.g., Ratcliff & McKoon, 1995). Since target odors in Experiment 2 were processed faster via the right nostril, and priming odors in Experiment 1 were processed faster via the left nostril, it is not likely that episodic recognition was responsible for the latency reductions in Experiment 1. This picture was confirmed by an ANOVA on response latencies showing a two-way interaction effect between test (priming vs. target odors) and nostril used at test [$F(1,124) = 8.380$, $p < .005$].

Does the kind of priming seen here match olfactory ecology? Although a gain of 200 msec might seem large as effects of priming go, does it offer any advantage? This remains to be seen. Few life-and-death decisions in the domain of human olfaction will depend upon a span of 200 msec, but the priming manifested here may constitute only an aspect of a larger set of phenomena relevant to implicit learning and memory. Koenig et al. (2000) found a gain of 400 msec against a baseline of about 3,500 msec for decisions of edibility. Those investigators have gone so far as to argue for an "olfactory pattern activation subsystem" akin to the subsystems proposed for visual and auditory perceptual representation systems. We take their result and ours at this time principally as experimental demonstrations that implicit memory for odors can occur. How such memory manifests otherwise remains to be explored. We can note that the well-known Proustian effect, whereby an odor can

recreate the distant past, complete with sights, sounds, and emotions, would seem on its surface to involve implicit processes. Others have explored phenomena of relevance to that experience, with reasonable success (see Köster, Degel, & Piper, 2002). Smell may, as usual, bring up the rear, but in the case of implicit memory it may have some unique dimensions to add to the corpus of results.

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