Research Article

The Mind's Nose

Effects of Odor and Visual Imagery on Odor Detection

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ABSTRACT—*We examined odor imagery by looking for its effects on detection of weak odors. Seventy-two healthy subjects performed a forced-choice odor detection task in one of three conditions: after being told to imagine an odor (odor imagery), after being told to imagine an object (visual imagery), or without having received imagery instructions (no-imagery control). For the two imagery conditions, the presented and imagined stimuli were either the same (matched) or different (mismatched). There was a significant difference between detection in the matched and mismatched conditions for odor imagery, but not for visual imagery. We conclude that our paradigm does measure odor imagery and that the effect of imagery on detection is both content- and modality-specific. Further, the difference between conditions was due to lower detection with mismatched odor imagery than without imagery, indicating that interference underlies the effect.*

Some people say that they are able to imagine different odors, such as the smell of freshly cut grass or the smell of strawberries. Many others, however, say that they cannot imagine odors no matter how hard they try; some conclude that, therefore, odor imagery is not possible. The main aim of this study was to move this discussion away from self-report and to address these questions by experimental manipulations.

Mental imagery refers to the evocation or creation of mental representations that are not initiated by external stimuli, but by the imager's will. One of the first experimental studies of mental imagery was published by Perky (1910). She demonstrated that people tended to misinterpret very weak visual stimuli as their own mental images. The evidence for the existence of mental imagery came much later, using methods derived from the signal detection model (Segal & Fusella, 1970). Over the past few decades, mental imagery has gradually become a very active area of research. Overall, imagery is a well-documented phenomenon, particularly in the visual (e.g., Alivisatos & Petrides, 1997; Kosslyn, Ganis, & Thompson, 2001; Thompson & Kosslyn, 2000), auditory (e.g., Halpern & Zatorre, 1999; McGuire et al., 1996), and motor (e.g., Jeannerod, 1994; Parsons et al., 1995) modalities, but it has been studied far less in olfaction and taste.

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Mental imagery is a controversial topic in the case of olfaction. Whereas some investigators believe that olfactory imagery is widespread in the general population (Gilbert, Crouch, & Kemp, 1998), others have come to the conclusion that people are not able to generate odorlike mental images (Crowder & Schab, 1995; Engen, 1982, 1987). Some experimental findings support the existence of odor imagery (Ahsen, 1995; Algom & Cain, 1991; Algom, Marks, & Cain, 1993; Carrasco & Ridout, 1993; Gilbert et al., 1998; Levy, Henkin, Lin, Hutter, & Schellinge, 1999; Lyman & McDaniel, 1990), but others do not (Crowder & Schab, 1995[1]; Elmes & Jones, 1995; Herz, 2000; Schab, 1990). It is possible that published studies do not reveal the whole picture, because studies with significant findings are more likely to be published than those without.

In addition, various criticisms have been directed at those studies that have reported positive findings. Studies using a questionnaire or self-report approach (Ahsen, 1995; Gilbert et al., 1998) are generally seen as providing insufficient basis for reliable conclusions; in too many areas of psychology, self-report has not led to the most accurate picture of the studied phenomenon. Crowder and Schab (1995) put this objection into a succinct statement that "experience is not evidence" (p. 94).

Several investigators designed experimental paradigms to try to study odor imagery more objectively. Most of these paradigms had already been successful in demonstrating imagery in other sensory domains (primarily visual), and they were adapted for studies of imagery in the olfactory modality (Algom & Cain, 1991; Carrasco & Ridout, 1993; Lyman & McDaniel, 1990). Although carefully designed and methodologically sound, these studies of odor imagery have been criticized as providing inconclusive findings. The main objection has been semantic mediation: Some authors (Crowder & Schab, 1995; Elmes, 1998; Herz, 2000) have argued that it is not clear whether the alleged odor images were perceptual or propositional, that is, whether they were odorlike rather than verbal-like experiences. Furthermore, some studies have been criticized for using rating measures (Algom & Cain, 1991; Algom et al., 1993; Carrasco & Ridout, 1993); the concern is that subjects' responses in these studies may have reflected the influence of explicit knowledge of olfactory principles rather than operation of odor imagery. In summary, even studies that had provided supportive evidence for the existence of

[1]Crowder and Schab (1995) reported three different experiments in which they attempted, and failed, to demonstrate that people are able to imagine odors.

odor imagery have been questioned on both theoretical and methodological grounds, leaving the debate on odor imagery unresolved.

We decided to study imagery by measuring its effects on detection of weak signals, an approach that has been used successfully in vision and audition. Several studies have demonstrated that detection of weak, perithreshold signals can be manipulated by introducing mental imagery (Farah, 1985; Farah, Péronnet, Gonon, & Giard, 1988; Farah & Smith, 1983; Segal & Fusella, 1970). Crowder and Schab (1995) applied this same idea in an experiment on olfaction. They reported negative findings, and concluded that people cannot create images of odors. However, we argue that the lack of an effect in Crowder and Schab's experiment could be explained by some procedural factors rather than people's inability to image odors. These factors include the decision to measure detection threshold: When threshold is measured, the intensity of presented stimuli varies, and this makes it difficult for the effect of imagery to be revealed. Hence, we decided to keep the concentration of odors to be detected at a constant level, and within the range of 60 to 80% detection accuracy. Thus, we measured each participant's detection threshold for our experimental odors, and then presented the odors at each individual's threshold level in the detection task of the main experiment. We chose to measure thresholds using a single-staircase procedure because data from the literature suggested that detection will be at approximately 71% accuracy when the detection threshold is established using this method (Doty, 1991a, 1991b; Wetherill & Levitt, 1965).

The other procedural factor that probably led to the lack of an effect in Crowder and Schab's (1995) study was the comparison of detection with matched imagery and detection without any imagery. Previous studies in vision (Farah, 1985; Farah et al., 1988) and audition (Farah & Smith, 1983) have demonstrated that the effect mental imagery exerts on detection is not large, and that the best way to capture it is by comparing matched- versus mismatched-detection conditions rather than matched detection versus detection without imagery.

Thus, in the present study, we measured the accuracy of odor detection: Odors to be detected were either matched or mismatched with simultaneously imagined odors. We also explored the specificity of the effect by introducing a control; we chose to use a visual imagery condition with exactly the same task requirements as the odor imagery conditions, except that subjects would be asked to imagine what the named objects looked like instead of what they smelled like. In addition, we examined the direction of the effect of imagery on detection by including a no-imagery condition and comparing it with the matched and mismatched conditions. Another question addressed by our study was the relationship between an objective and a subjective (self-report) measure of odor imagery, and possible gender differences on these measures. Finally, we examined the individual variation in odor imagery ability in normal, healthy participants.

METHOD

Subjects

Seventy-two subjects participated in this experiment. All subjects reported normal ability to smell. Potential subjects were excluded if they had respiratory infections, allergies leading to nasal congestion, a history of neurological or psychiatric disease, or other conditions leading to impaired sense of smell. Subjects were randomly assigned to one of three conditions (n = 24 in each): odor imagery, visual imagery, or no imagery. All participants were undergraduate students at McGill University, in Montreal, Canada. The composition of the three groups was similar with respect to age (Ms = 19.6, 21.6, and 19.4, range: 17–25), gender (12, 13, and 14 women, respectively), and smoking status.

Stimuli and Materials

Two odors were used: phenyl ethyl alcohol (PEA), a substance that smells like roses, and Citral, a substance that smells like lemons. Odorless diethyl phthalate was used as a blank stimulus and as a diluent for the threshold series (which consisted of 14 concentrations that ranged from −7.5 to −1.0 log steps and differed by half-log steps; i.e., 3.162-fold serial dilutions were used).

For the visual imagery condition, a picture (color photograph) of a rose and a picture of a lemon were used in an imagery practice session.

In addition to olfactory testing, questionnaires asking for ratings of the vividness of odor or visual images were administered: the Vividness of Olfactory Imagery Questionnaire (VOIQ; Gilbert et al., 1998) and the Vividness of Visual Imagery Questionnaire (VVIQ; D.F. Marks, 1973).

Procedure

Each subject was assigned to one of the three conditions (odor imagery, visual imagery, or no imagery) and given four (or three) consecutive blocks of tasks, depending on the condition.

The first step in all three conditions was to determine detection thresholds for the two odors for each subject, using the single-staircase procedure (Doty, 2000). This procedure involves an ascending method; increasing odorant concentrations are presented until a concentration that can be detected reliably (i.e., correct response on five consecutive trials) is established. At that point, a lower concentration is presented (first reversal), and testing continues using a two-up-one-down method until seven reversals of direction are completed. The threshold is calculated as the mean concentration of the last four of the seven reversals.

Next, subjects in the imagery conditions underwent a brief imagery practice. Participants in the odor imagery condition received odor imagery practice: PEA and Citral (the strongest concentrations from the threshold series) were presented individually and named as "rose" and "lemon odor." After introducing each odor, the experimenter removed it and requested that the participant imagine that odor in his or her mind's nose. The exercise was repeated until the subject asserted that he or she was able to form the olfactory image of each odor or until three presentations were made. Subjects assigned to the visual imagery condition underwent a visual imagery practice: The procedure was the same, except that they were shown pictures of a rose and a lemon, and when the pictures were removed, the experimenter requested the subjects to picture the rose and lemon in their minds' eye.

After the imagery practice, subjects were asked to fill in imagery questionnaires (VOIQ in the odor imagery condition, VVIQ in the visual imagery condition). Subjects in the no-imagery condition completed both the VOIQ and the VVIQ after their detection thresholds were measured.

The main part of the study comprised forced-choice detection trials. On each trial, one of the two odorants (a lemon- or a roselike smell)

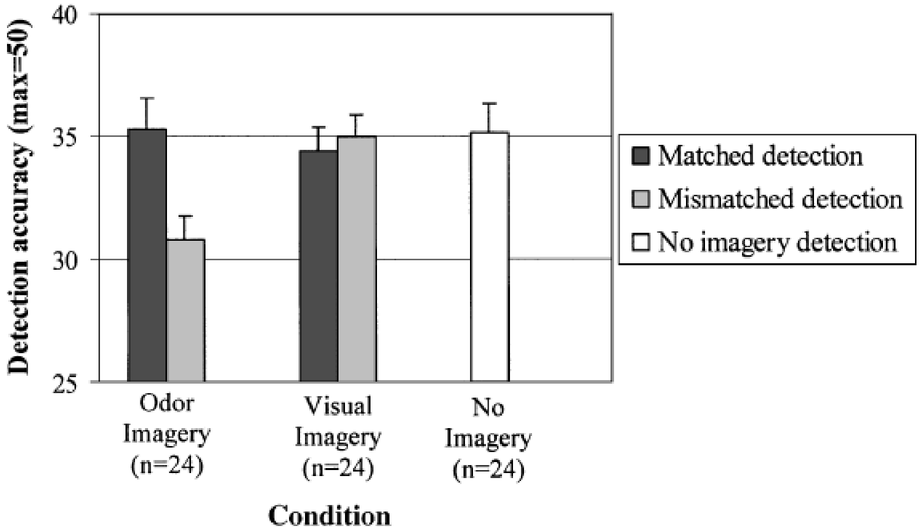

Fig. 1. Accuracy of odor detection in the three imagery conditions. For the odor and visual imagery conditions, results are shown separately for matched and mismatched trials.

and a blank (odorless) stimulus were presented, and the subject had to decide which one smelled stronger. All odorants were presented at the subject's detection threshold level. In the imagery conditions, subjects were asked to imagine an odor (odor imagery) or a picture (visual imagery) of either a rose or a lemon before sniffing each bottle. In 50 detection trials, the presented and the imagined stimuli were the same (matched detection trials), and in 50 trials, the two stimuli were different (mismatched detection trials). Subjects in the no-imagery condition were given 50 detection trials and were not asked to imagine anything before they sniffed each bottle.

RESULTS

Detection of Weak Odors During Odor Versus Visual Imagery

In order to explore the effect of odor and visual imagery on odor detection, we conducted a 2×2 analysis of variance (ANOVA) with detection (matched vs. mismatched) as a within-subjects factor and imagery (odor vs. visual) as a between-subjects factor. First, gender (women vs. men) and odor (lemon vs. rose) were analyzed as other between- and within-subjects factors, respectively. No significant interactions or main effects of gender or odor were found. Therefore, women and men, and rose and lemon odors, were collapsed together in further analyses. The results showed a significant interaction between imagery and detection, $F(1, 46) = 6.87$, $p < .05$ (Fig. 1). Simple effects showed that the difference between matched and mismatched detection was significant when people engaged in odor ($p < .01$), but not visual ($p > .05$), imagery.

Matched- and Mismatched-Detection Trials: Comparison With No-Imagery Trials

To address whether facilitation or interference underlies this effect, we compared detection with no imagery with matched and mismatched odor detection during odor or visual imagery. A one-way ANOVA comparing matched odor, matched visual, and no-imagery detection (Fig. 1) did not reveal any differences, $F(2, 69) = 0.19$, $p > .05$.

In contrast, the means of mismatched odor, mismatched visual, and no-imagery detection were significantly different (Fig. 1) as revealed by ANOVA, $F(2, 69) = 5.93$, $p < .01$. Post hoc pair-wise comparisons (Tukey HSD) showed that the significant differences were between mismatched odor imagery and mismatched visual imagery detection ($p < .05$) and between mismatched odor imagery and no-imagery detection ($p < .01$).

Relation Between a Subjective and an Objective Measure of Odor Imagery

One of the aims of this study was to provide a behavioral measure of odor imagery. The paradigm used allowed us to calculate an odor imagery index (OII) for each subject individually: OII represents the difference between matched and mismatched detection during odor imagery. We looked at whether the OII was related to a subjective measure of odor imagery (VOIQ score). The correlation between OII and VOIQ was not significant when calculated across the whole sample ($r = -.25$, $p > .05$, $n = 24$).[2] However, when we looked at correlations between the two measures as a function of gender, the correlation was significant in women ($r = -.61$, $p < .05$, $n = 12$), but not in men ($r = .01$, $p > .05$, $n = 12$). This difference between women and men is interesting given that women and men did not differ on either of the two measures separately, $t(22) = 0.29$, $p > .05$, and $t(22) = 1.06$, $p > .05$, for the OII and VOIQ, respectively.

Individual Differences in Odor Imagery Ability

The distribution of the individual OII scores showed a large variation in our sample (Fig. 2). In addition, not all subjects show the predicted superiority of matched over mismatched odor detection. In fact, only a sizable minority of subjects showed a large effect of odor imagery on

[2]We expected to find a negative correlation between the two measures because higher OII scores indicate better odor imagery ability, whereas higher VOIQ scores indicate poorer odor imagery ability.

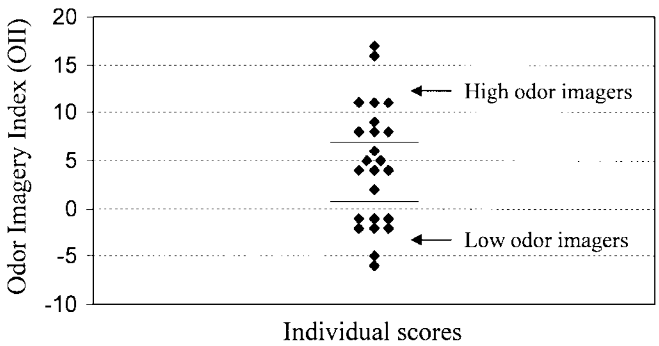

Fig. 2. Individual differences in odor imagery ability. Each diamond represents the Odor Imagery Index (OII) calculated for 1 subject (by subtracting mismatched odor detection from matched odor detection). The graph shows a tertiary split of the sample ($n = 24$) based on the OII. This approach permits classification of participants into ''high,'' ''medium,'' and ''low'' odor imagers.

odor detection, and those could be characterized as "good" or "high" odor imagers. Figure 2 shows a tertiary split of our sample based on the OII.

DISCUSSION

Measuring effects of imagery on detection of weak signals, we found that odor imagery exerts a content-specific effect on odor detection: Subjects were more likely to detect weak odors when the imagined and the presented odor were the same (matched) than when the two were different (mismatched). Furthermore, this effect of imagery on odor detection is not only content-specific but also modality-specific: The difference between matched and mismatched detection was significant for odor, but not for visual, imagery. Rose and lemon odors were selected because of their presumed familiarity to the general population, and our findings showed that these two smells were equally imaginable: The effect of imagery was equivalent for the two odorants.

The interaction between type of imagery (odor, visual) and detection (matched, mismatched) is important because it clearly shows that the matched-versus-mismatched effect is specific to odor imagery. The lack of an effect in the visual imagery condition eliminates the possibility that the difference between matched and mismatched detection is a generalized effect of mental imagery. Furthermore, the lack of effect in the visual imagery condition indirectly excludes other general explanations of the effect, such as attentional or semantic mediation.

If the instruction to imagine odors induced allocation of attention to the olfactory channel whereas the instruction to imagine objects resulted in allocation of attention to the visual channel (i.e., away from the olfactory channel), there should have been a main effect of imagery, that is, better performance with odor imagery than with visual imagery regardless of whether the imagined and detected stimuli were matched or mismatched. However, this result was not obtained: There was no main effect of imagery.

Another possibility is that detection of a target stimulus is enhanced when that target is selectively attended to (i.e., selective attention), relative to when any stimulus from that sensory modality is attended to. This enhancement of detection by attention has been demonstrated in other sensory modalities, such as vision (Luck et al., 1994), audition (Hafter, Schlauch, & Tang, 1993), and taste (L.E. Marks & Wheeler, 1998a, 1998b), but not for smell (Ashkenazi & Marks, 2002). Ashkenazi and Marks suggested that the capacity to attend selectively to weak olfactory stimuli is intrinsically limited. Even if selective attention were operating for smells, the procedure in the present study and the typical procedure used to examine the effects of attention or expectation on detection of weak stimuli are sufficiently different to preclude analogy. Specifically, our procedure differed from the paradigms typically used to address the role of attention in that we did not instruct or lead subjects to expect one stimulus and not the other, and the probability of occurrence for the matched and mismatched stimuli was equal (i.e., 50%). Finally, some previous studies have shown that the effect of selective attention on detection can be elicited by cues that are not content-specific (e.g., spatial cues for visual stimuli; Luck et al., 1994) or modality-specific (visual cues for auditory stimuli; Hafter et al., 1993). The effect reported in the present study was both content- and modality-specific, which led us to conclude that we captured the effects of odor imagery.

We also do not think that semantic mediation is responsible for the effect we found. One reason is that in detection of weak signals, semantic mediation does not seem to present a relevant confound. It is unclear how propositional thinking about an item and its features would influence detection of very weak (threshold) stimuli. In our experiment, participants were not informed of what stimuli were being presented. On each detection trial, the odor stimulus was at the individual's detection threshold, which was usually below the odor-quality recognition threshold for olfaction (Doty, 1991b; Doty & Kobal, 1995). In this context, it would be difficult to explain how verbal codes referring to an item would change detection of that item's smell at the barely detectable intensity level. Finally, we would argue that semantic mediation was equal in the odor and visual imagery conditions, and therefore cannot account for our results.

The results of the present study are consistent with the findings of Lyman and McDaniel (1990): Both studies showed that odor imagery exerts a stronger effect than visual imagery on another olfactory process (odor detection in this study, odor recognition memory in theirs). Other researchers have also tried, without success, to show that odor imagery has greater effects than visual imagery on odor recognition memory (Crowder & Schab, 1995) or odor identification (Crowder & Schab, 1995; Elmes & Jones, 1995). The main idea behind this group of studies is that if odor imagery exists, it ought to exert greater effects on certain olfactory-related processes (e.g., odor detection, odor recognition memory) than visual imagery does. Overall, this approach to studying odor imagery has yielded limited results so far. We believe that the special combination of olfaction and mental imagery (each being a process with its own complexities) results in a mental activity difficult to engage in, and even more difficult to study behaviorally.

Previously, Crowder and Schab (1995) reported an experiment in which they examined the effect of odor imagery on detection of weak odors. Our notion that two procedural aspects of Crowder and Schab's study were responsible for their negative results was confirmed by our findings. The first modification that we made to Crowder and Schab's paradigm was to keep the detection accuracy at a constant level, that is, at 71% (Wetherill & Levitt, 1965). Our results are entirely consistent with Wetherill and Levitt's calculations, as detection accuracy without imagery was 70.3% in the present study. The second modification that we introduced was to measure the imagery effect by the difference between matched and mismatched detection, rather than the difference between matched and no-imagery detection. This also proved to be important for demonstrating an effect of odor imagery: The comparison between matched and no-imagery detection, which did not reveal differences in Crowder and Schab's study, also showed no differences in ours. These results for olfaction are consistent with results reported previously for vision; detection of faint visual stimuli was equally accurate with a matching image and with no image (Farah et al., 1988).

One of the questions addressed in our study is whether women and men differ in odor imagery ability. Various olfactory measures show a gender effect, and it is usually women who have the superior performance. The sizes of these differences tend to be small, but they have been reported sufficiently often that the gender effect in olfaction has become widely accepted (and expected). Furthermore, two previous studies of odor imagery suggested gender differences in olfactory imagery (Crowder & Schab, 1995; Levy et al., 1999). With the present paradigm, we did not find any differences on the behavioral or self-report measure of odor imagery. However, the objective and subjective measures of odor imagery correlated differently in women and men: Women showed a significant correlation between the two measures of odor imagery, whereas men did not. These results raise the possibility that women are better than men at evaluating their own odor imagery ability, even though women and men do not differ in imagery itself (measured either subjectively or objectively). In other words, women showed a tendency toward having better insight than men into their odor imagery ability. Because these results were obtained with a small sample, replication is needed before a firmer conclusion can be established.

We also examined the direction of the effect of odor imagery on odor detection. The results pointed to interference, because detection with mismatched odor imagery was worse than detection with no imagery. Imagining an odor different from the one being detected interferes with detection, whereas imagining the same odor as the one being detected does not facilitate detection. This result is consistent with that of Crowder and Schab (1995) for olfaction (no difference between matched and no-imagery detection) and with that of Farah et al. (1988) for vision (equal detection accuracy with a matched image and with no image, but significantly worse detection with a mismatched image than with no image). Similarly, Segal and Fusella (1970) compared the effect of imagery in two modalities (audition and vision) and reported that interference was greater within the same modality than across modalities. We found the same: Mismatched odor imagery interfered with odor detection, whereas mismatched visual imagery did not. It seems that results from this and other studies consistently suggest that mismatched imagery interferes with the detection of weak stimuli, and this is the case in vision, audition, and olfaction. However, although odor imagery can cause interference in odor detection, interference may not be observed for odor processes other than detection. For example, Lyman and McDaniel (1990) showed that imagining an odor facilitates subsequent recognition of it.

In summary, behavioral findings reported here are consistent with some previous behavioral (Algom & Cain, 1991; Algom et al., 1993; Carrasco & Ridout, 1993; Lyman & McDaniel, 1990), neurophysiological (Lorig & Roberts, 1990), and neuroimaging (Levy et al., 1999) studies. Findings from these approaches provide converging evidence supporting the existence of odor imagery. Olfactory mental images therefore are yet another type of mental image that can now be studied experimentally, together with images in vision (Kosslyn et al., 2001), audition (Halpern & Zatorre, 1999), and motor performance (Jeannerod, 1994).

Finally, this study found large individual variation among healthy people in the ability to imagine odors. One of the strengths of the present approach is that it permits objective classification of subjects into high and low odor imagers, which may be useful for future investigations. As in some studies (Crowder & Schab, 1995; Schab, 1990), but not others (Lawless, 1997; Schab & Cain, 1991), all participants who completed the odor imagery condition in our study claimed that they were able to generate odor images. Our results suggest that, regardless of self-report, some people are able, and others are not able, to create mental images of odors.

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