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Olfactory test performance and its relationship with the perceived location of odors

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Abstract Odors are generally perceived as arising via the nose when sniffed and as part of an orally located flavor during ingestion. The perceived location of an odor may in part be an attentional phenomenon, with concurrent oral stimulation occurring at the expense of access to the olfactory channel. Two predictions were derived from this account: (a) tasks dependent on a capacity to attend to the olfactory channel—odor discrimination and naming—should be adversely affected by oral localization; and (b) tasks not dependent upon a capacity to attend—incidental learning/recognition memory—should not. Using a procedure to generate oral localization, in which odors were presented via the nose with concurrent oral stimulation (sucrose, a viscous fluid or water), greater reported oral localization was associated with poorer odor discrimination and naming, but not with recognition memory performance. These results support the notion that attentional processes contribute to oral localization of odors by reducing the capacity to attend to the olfactory channel.

Keywords Odor · Flavor · Localization · Discrimination · Naming · Memory · Attention

The sense of smell is usually associated with sniffing via the nose, yet olfaction has a significant and unappreciated role in the perception of food and drink (Rozin, 1982). When a food is placed in the mouth, volatile chemicals ascend via the nasopharynx (retronasal olfaction), stimulating the same receptor sheet activated during sniffing (orthonasal olfaction). Although orthonasal odors are perceived as "smells" sensed by the nose and originating in the environment, retronasal presentation, which is usually accompanied by somatosensation (e.g., chewing) and taste (e.g., sugar), is perceived as an orally located flavor or "taste." At least two factors contribute to the binding of orthonasal input to the nose/environment, and of retronasal input to the mouth/flavor. One factor is the difference in nasal air-flow direction between these two delivery modes (Heilmann & Hummel, 2004; Hummel et al., 2006; Small, Gerber, Mak, & Hummel, 2005). This difference may be detectable via the olfactory receptor sheet and by somatosensory receptors in the nose (e.g., Frasnelli, Heilmann, & Hummel, 2004; Scott, Acevedo, Sherrill, & Phan, 2007). Another factor concerns attention (Stevenson, Mahmut, & Oaten, 2011). When oral stimulation occurs (i.e., taste, somatosensation), this may promote oral localization by impairing the ability to attend to the olfactory channel, resulting in the odor being perceived as a flavor or "taste" sensation, rather than as a "smell." Accordingly the perceived location of an odor should reflect the capacity to attend to it. If this is correct, then tasks requiring attention to the olfactory channel should be performed less efficiently when an odor is localized to the mouth relative to the nose. In the present study, we tested this hypothesis.

Von Bekesy (1964) found that an odor presented orthonasally (i.e., sniffing) could be perceived as taking a variety of locations from the tip of the nose, via the back of the throat to the mouth, dependent on its delivery time relative to a taste presented to the mouth. These findings suggested that oral localization was maximal when a taste and odor were presented simultaneously. Although this

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implies that orally localized odors can be detected as smells, this is clearly not the norm. The sensations generated during eating and drinking are casually referred to as "taste" or "flavor," and there is little or no awareness of olfaction's major role in this process in most people (Rozin, 1982; Stevenson, 2009). This may in part be an attentional phenomenon. Recent variants of the von Bekesy (1964) technique suggest that a more salient oral stimulus such as a taste is more effective at generating oral localization than is water or a viscous fluid (Lim & Johnson, 2011; Stevenson, Oaten, & Mahmut, 2010). More direct manipulations of salience by varying odor and taste intensity have the expected effect on oral localization of odors. Making the odor more salient reduces oral localization, whereas making taste more salient increases it (Stevenson, Mahmut, & Oaten, 2011). Further evidence comes from studying patients who have difficulty in voluntarily attending to the olfactory channel. Such patients should be especially prone to oral localization when compared to normal controls, and Tham, Stevenson, and Miller (2011) found that this was, in fact, the case. Finally, when a taste and odor are presented simultaneously to the mouth, participants appear unable to benefit on a detection task from selectively attending to the olfactory channel (Ashkenazi & Marks, 2004), even though selective attention is clearly beneficial in various orthonasal tasks (e.g., Spence, McGlone, Kettenmann, & Kobal, 2001). This would seem to suggest that when attention is successfully captured by events detected in the mouth, this occurs at the expense of attention to the olfactory channel. It may be this that leads participants to conclude that all concurrent chemosensory input is arising from their mouths, and for their failure to appreciate the role that olfaction plays in flavor.

If oral localization of odors does occur because participants do not or cannot attend to the olfactory channel, then tasks that require attention to the olfactory channel should be impaired when an odor is localized to the mouth. Conversely, olfactory tasks that are not reliant on attention should be unaffected by the odors' apparent location. Odor discrimination and naming were selected as tasks likely to require attention, with incidental odor learning/memory as a task unlikely to require attention. This latter claim was based on the finding that both retronasal and orthonasal experiences may be effortlessly encoded (e.g., Degel & Koster, 1999; Issanchou, Valentin, Sulmont, Degel, & Koster, 2002; Stevenson, Boakes, & Wilson, 2000). We thus hypothesized that greater oral localization of odors, reflecting a more limited ability to attend to the olfactory channel, would be associated with impaired odor discrimination and naming, whereas incidental odor learning—and, thus, the later ability recognize these odors—would not.

A major issue in testing the impact of oral localization on discrimination, naming, and incidental learning/recognition memory concerns the variation in oral localization response observed when using the von Bekesy type technique. Although sucrose in the mouth is more successful at generating oral localization than is somatosensory cues such as viscosity, and this in turn is more effective than water, in each case, there is significant variation in oral localization response (e.g., Lim & Johnson, 2011; Stevenson, Oaten, & Mahmut, 2010; Stevenson, Mahmut, & Oaten, 2011). One approach, then, to address the effect of oral localization on olfactory performance is to give participants different oral stimuli—water, viscous fluid, and sucrose—and then compare the impact of this on localization judgments and on their olfactory performance. Although we incorporated this approach in the present study, we suspected it would not produce a sufficient difference in localization judgments between groups, which led us to consider a second approach. In the present study, localization judgments were treated as a continuous independent variable, with the mouth manipulations necessary to promote the presence or absence of oral localization treated as a further independent variable. These variables were then used to predict variation in olfactory test performance using regression. Incorporating this second approach into the design raised a further issue. If the target odors are fully counterbalanced across tasks (i.e., different participants receive different sets of odors for naming, discrimination, and incidental learning/recognition memory), any relationship with localization might reflect differences in the target set (e.g., harder-to-name odors could be more susceptible to oral localization). To reduce this possibility, the same sets of food-related odors (since these may be most susceptible to oral localization) were consistently employed for each task.

Method

Participants

A total of 122 healthy participants who were naive to the purpose of the study took part either for course credit or for a small cash payment, and were randomly allocated to one of three mouth conditions. A total of 119 participants successfully completed the study. Three participants were lost because of their inability to hold solutions in their mouth while simultaneously breathing through their nose. Participant characteristics by mouth condition were water in the mouth (n = 40; 18 female; mean age = 25.1 years), viscous solution in the mouth (n = 40; 22 female; mean age = 23.8 years), and sucrose in the mouth (n = 39; 23 female; mean age = 21.6 years).

Stimuli

Mouth stimuli were all presented at room temperature (22°C) in 10-ml aliquots in transparent disposable sample cups. Sucrose was presented as a 0.35 M solution. The viscous solution (odorless and tasteless carboxy methylcellulose; de Araujo & Rolls, 2004) was prepared by dissolving 20 g of carboxy methylcellulose (CMC) in stirred warm water, making this up to 1 liter (low viscosity CMC; Sigma-Aldrich, Sydney; 50–200 cP). Tap water was used in the water condition (and in the preparation of the sucrose and viscous solutions).

Odorants were presented in visually identical opaque plastic squeezy bottles. The undiluted odorant at the indicated weight (see Table 1) was applied to a cotton–wool ball and placed inside the squeezy bottle. For certain odorants, the weighed stimulus was wrapped in a cotton–wool shell and placed in the squeezy bottle. Following pilot work to establish similar levels of intensity across stimuli, odorants were randomly allocated into three sets for use in this study (see Table 1).

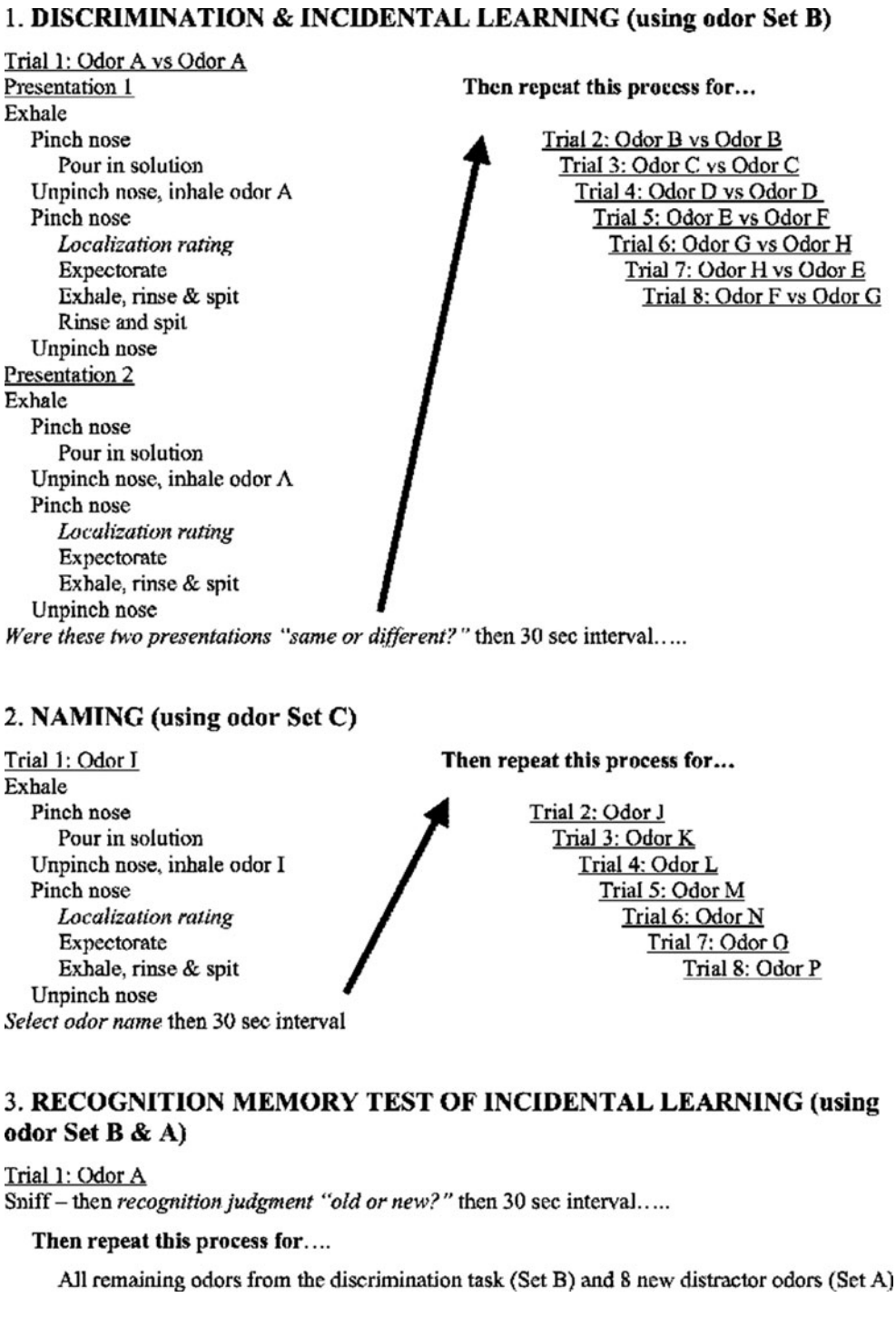
Procedure

Overview Diagram 1 presents a summary overview of the procedure. Each participant undertook the same procedures in the same order, the only difference being the solution that they placed in their mouths on certain tasks. Importantly, odors were only ever presented orthonasally during the experiment, but this was never made known to participants. Participants completed a discrimination test (also serving to incidentally present odors for the later recognition memory test), followed by an odor-naming test, both of which were conducted with odors presented to the nose while one type of solution was held in the mouth (either water, sucrose, or viscous, depending on the condition to which the participant had been randomly allocated). Finally, participants completed a recognition memory test, which involved just sniffing odors not encountered in the experiment before, and "old" odors presented in the discrimination test. The whole procedure took around 60 min to complete.

Table 1 Odorants used in the study

Set and Odorant	Quantity	Source (reference number)
Set A		
Strawberry	0.075 g	Quest (DC12350)
Carvone (Mint)	0.050 g	Dragoco (3/918883)
Lychee	0.075 g	Quest (APO5102)
Ground coffee	7.5 g	Harris premium brand
Cinnamon oil	0.18 g	Sigma-Aldrich (C-7267)
Eugenol (oil of cloves)	0.075 g	Sigma-Aldrich (E-5504)
Longan (tropical fruit)	0.13 g	Dragoco (9/H03479)
Banana	0.1 g	Quest (DC11948)
Set B		
Pear	0.25 g	Quest (APO6882)
Lemon oil	0.18 g	Sigma-Aldrich (WC26250-1)
Aniseed	0.15 g	Quest (DC11177)
Orange oil	0.18 g	Sigma-Aldrich (W28253-7)
Cherry	0.1 g	Quest (DC12790)
Nutmeg	5.0 g	Homebrand
Lime	0.13 g	Quest (DC11570)
Kiwifruit	0.1 g	Dragoco (903188)
Set C		
Almond	0.2 g	Maharajas choice
Caramel	0.075 g	Dragoco (9/013999)
Grape	0.15 g	Quest (APO5751)
Grapefruit	0.18 g	Quest (APO6256)
Red bean (sweet/curd-like)	0.13 g	Quest (APO5721)
Dried ginger	5.0 g	Homebrand
Guava	0.075 g	Dragoco (9/H04190)
Plum	0.075 g	Quest (DC16189)

Diagram 1 Overview of the procedure



Discrimination task The discrimination task used odorants drawn solely from Set B (see Table 1). For each participant, a different combination of odors was randomly drawn from Set B, so that eight pairs were created for that participant, composed of four same pairs (i.e., odorants a vs. a, b vs. b, c vs. c, d vs. d) and four different pairs (i.e., odorants e vs. f, g vs. h, h vs. e, f vs. g). The only other constraint was that each odor had to occur twice. The order of pair presentation and of trials was randomized separately for each participant.

Each discrimination trial was composed of two odor presentations. Participants were first trained so that they could learn the sequence of events and the actions, which were common to each presentation and trial. The procedure on each trial involved the following steps, which were carefully choreographed by the experimenter. First, partic-

ipants exhaled and then poured their target solution (dependent upon experimental condition) into their mouths while their nose was pinched shut by their nondominant hands. Second, the experimenter brought the sniffing bottle so that the spout pointed at their noses, which they then unpinched and inhaled (2–3 secs) once, while the experimenter squeezed and puffed the bottle three times in quick succession. Third, the nose was then repinched, and participants were asked to judge whether they thought the odor had come from the bottle or the cup. This rating was made on a 7-point scale from 1 (*Definitely Bottle*) to 7 (*Definitely Cup*). The nature of this scale was explained during training, so that a response of 4 indicated uncertainty over the source of the odor, ratings toward 1 reflected progressively greater certainty that the odor originated from the nose (i.e., the sniffing bottle), and ratings toward 7 reflected progressively greater certainty that the odor originated from the mouth (i.e., the cup). The participant made this rating by pointing to the number on a large version of the scale placed in front of them. After making this rating, participants expectorated the solution and then exhaled via their mouths. They then rinsed their mouths with water, expectorated, and only then was the nose unpinched. This process was then repeated for the second member of that trial. After the second presentation was complete (including its localization rating, etc.), participants were asked to judge whether the two presentations involved the same or different stimuli. Because the oral solution remained constant across all presentations, the principal difference between any pair of presentations, at least on "different" trials, was the presence of a different odorant. There was then a 30-s intertrial interval, after which the process described previously was repeated for the next pair, and so on, until all eight discrimination trials had been completed. This was then followed by a 5-min break.

Naming task The naming task always used odorants drawn from Set C. For each participant, the order of presentation of these eight odors was random. Each trial was completed as was described previously, except that after the localization rating had been made, participants were asked to select "the name of the odor they had experienced." This name was selected from a list of the eight target names (this list remained constant across trials). A 30-s interval separated each trial. After all eight trials had been completed, a 5-min break followed.

Incidental learning/recognition memory task This task assessed the degree of incidental learning that had taken place on the earlier discrimination task. The recognition memory test just involved sniffing odors. For each participant, all of the odors from Set B (the discrimination set) and all of the odors from Set A were presented in a different random order. The experimenter gave each participant three puffs of each odor to sniff, while they inhaled. This was followed by an "old" versus a "new" judgment, namely whether the odor had occurred during an earlier phase of the study (old) or whether its first occurrence was here on this task (new). A 30-s interval separated each trial.

Analysis

For the discrimination and recognition memory tasks a *d'* score, serving as the dependent variable, was calculated for each participant. For the recognition naming task, the number of correct name selections served as the dependent variable. Localization scores (serving as both dependent and independent variables, depending on the analysis) were calculated in three ways. First, on the discrimination task, the mean localization score across all 16 trials was calculated for each participant, and likewise for the eight trials of the naming task. Second, the number of trials on which a score of 5 or more was returned was calculated (i.e., the number of trials in which the participant reported localization to the mouth) both for the 16 trials of the discrimination task and for the eight trials of the naming task. Third, for the discrimination task only, the mean absolute difference between localization scores obtained for each presentation within a trial was calculated, so as to reflect average variability in localization performance within trials. Since the mean absolute difference score was highly correlated both with the mean localization score, $r(118) = 0.72$, $p < .001$, and with the mean number of oral localization trials score, $r(118) = 0.67$, $p < .001$, we regressed out the effect of these two variables from the mean absolute difference score. The resultant residual served as the measure of localization rating change within trials (hereafter termed the *residual difference score*). This allowed us to see the proportion of variance in discrimination performance accounted for by degree of localization, separate from the effect of changes in localization between each member of a trial.

For the first set of analyses, localization and olfactory performance scores were compared between the three mouth condition groups, followed by planned linear contrasts (water < viscous < sucrose; this ordering was based on those observed in several prior experiments; see Stevenson, Oaten, & Mahmut, 2010; Stevenson, Mahmut, & Oaten, 2011). Because there was a significant difference in age between these groups, $F(2, 116) = 3.70$, $MSE = 54.3$, $p < .05$, partial eta-squared = 0.06 (post hoc Bonferroni adjusted contrasts indicated that the water group was significantly older than the viscous group, no other difference being significant), age was included as a

covariate in all of these analyses (using SPSS 17 for Mac, as with all analyses in the present article).

The second set of analyses used regression. Here, the mouth condition group was coded into two dummy independent variables: taste versus no taste (i.e., sucrose vs. viscous and water), and greater oral stimulation versus weaker oral stimulation (i.e., water vs. sucrose and viscous). All of these data met the necessary assumptions for regression, and although localization data were skewed, corrective transformation (log; or recoding as a dichotomous variable) did not alter the reported outcome. The criteria for outlier elimination (which are all reported in the Results section) were a studentized residual greater than 3 *SD*s, a Cook's distance greater than 1, or a Mahlanobis distance with $p < .001$.

Finally, alpha was set at 0.05, but since some results were significant in one test but only marginally so in another ($p = .051$ to .099), such cases were also reported.

Results

Group comparison approach

Discrimination Data for each analysis below are presented in Table 2, by mouth condition group (water vs. viscous vs. sucrose). A univariate ANCOVA on mean localization scores on the discrimination task revealed a main effect of group, $F(2, 115) = 4.72$, $MSE = 1.13$, $p < .02$, partial eta-squared = 0.08, with a significant linear trend ($p < .005$) for greater oral localization increasing from water to the viscous fluid to sucrose (see Table 2). However, as can be seen in Fig. 1, there was considerable variability within each group in terms of the number of participants evidencing localization. Oral localization trial scores were analyzed in the same way, and a significant main effect of group was obtained, $F(2, 115) = 3.24$, $MSE = 8.05$, $p < .05$, partial eta-squared = 0.05, again with a significant linear trend ($p < .02$). Residual difference score also significantly differed by group, $F(2,115) = 3.11$, $MSE = 0.95$, $p < .05$, but there was no significant linear trend by group. Post hoc Bonferroni-adjusted contrasts revealed just one difference, between the water and viscous conditions (higher variability). We then tested whether the mouth condition group affected discrimination performance, but there was no significant effect.

Table 2 Means and standard deviations of localization and olfactory performance by group

Variable	Mouth Condition Group					
	Water		Viscous		Sucrose	
	M	*SD*	*M*	*SD*	*M*	*SD*
Discrimination trials						
Mean localization score	1.8	1.1	2.1	1.0	2.6	1.2
Oral localization trial score	1.3	2.9	1.9	2.5	2.9	3.1
Residual difference score	-0.3	0.8	0.3	1.0	0.0	1.1
Discrimination *d*'	1.2	0.6	1.2	0.9	1.3	0.6
Naming trials						
Mean localization score	1.6	1.0	1.9	1.2	2.2	1.2
Oral localization trial score	0.4	1.4	0.7	1.5	0.9	1.6
Naming score	3.6	1.4	3.6	1.6	3.6	1.6
Recognition memory test *d*' indexing earlier incidental learning						
	1.2	0.8	1.5	0.5	1.4	0.7

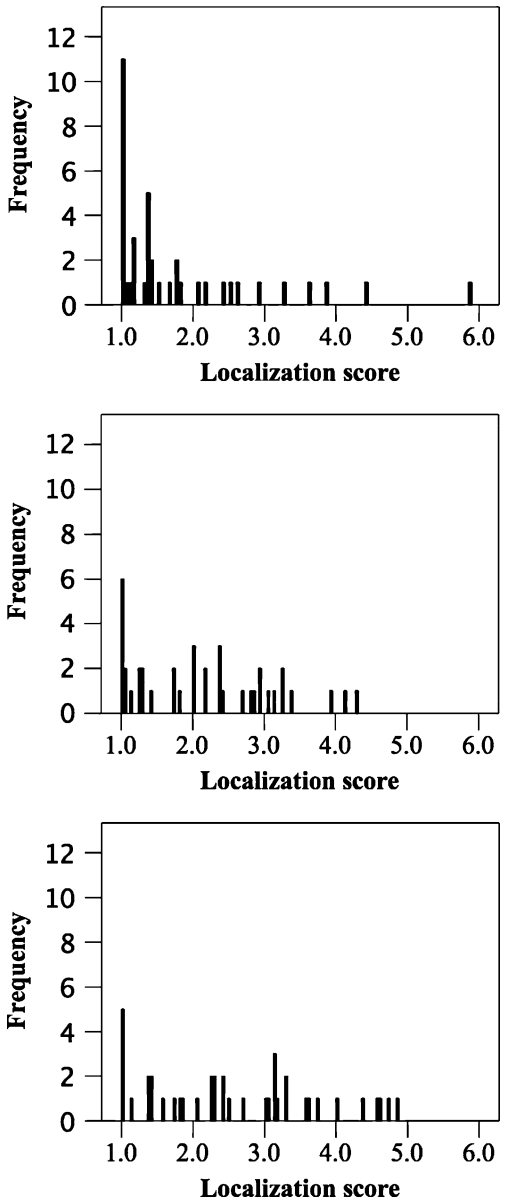


Fig. 1 Histogram of mean localization score for each participant (based on ratings for 16 odors) for the discrimination trials by mouth condition (top, water; middle, viscous; bottom, sucrose)

Naming On the naming task, mean localization score did not differ by group ($p = .088$), but a significant linear trend was evident ($p < .05$). Again, there was considerable variation within each group in degree of localization observed, as illustrated in Fig. 2. There was no effect of the mouth condition group on oral localization trial score for naming, or any effect of group on naming performance.

Incidental learning/recognition memory Group exerted no effect on this variable.

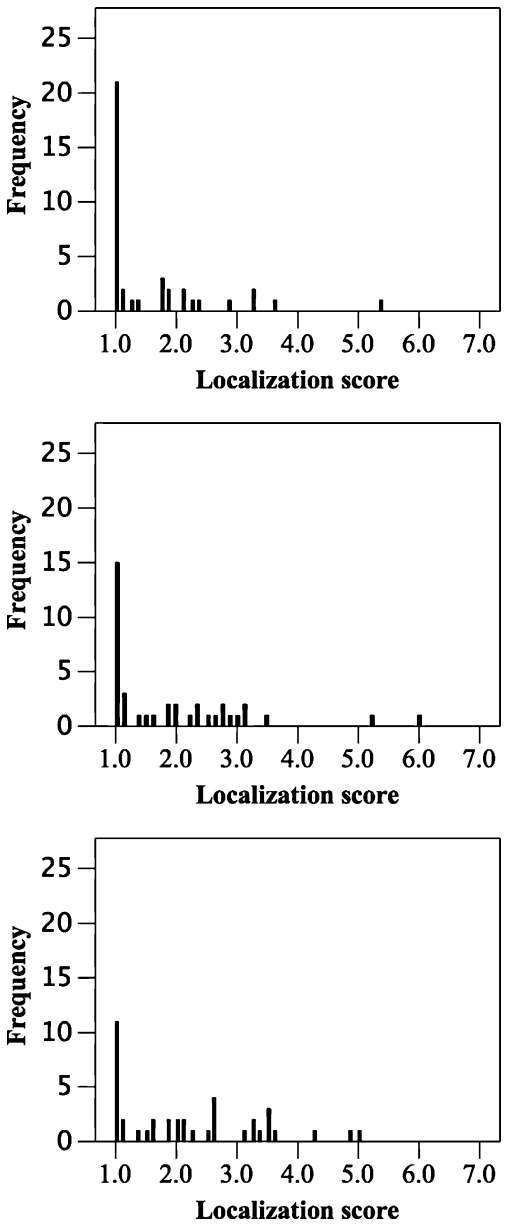


Fig. 2 Histogram of mean localization score for each participant (based on ratings for eight odors) for the naming trials by mouth condition (top, water; middle, viscous; bottom, sucrose)

Regression approach

Discrimination Pearson correlations were examined between discrimination performance and mean localization score, residual difference score, the mouth condition variables, gender, and participant age. Discrimination performance was negatively correlated with mean localization score, $r(118) = -0.28$, $p < .01$, and was marginally so with the oral localization trial score, $r(118) = -0.17$, $p = .06$, and the residual difference score, $r(118) = -0.17$, $p = .06$. Since the mean localization score was significantly associated with the oral localization trial score, $r(118) = 0.92$, $p < .001$, separate regression analyses were conducted with each variable.

Six independent variables—mean localization score, residual difference score, the two dummy variables, age, and gender—were then entered simultaneously into regression with backward elimination, with discrimination performance as the dependent variable. One case was excluded from this analysis because his predicted discrimination score differed from his actual score by 4 *SD*s (the inclusion of this case did not alter the conclusion of the analysis). The final model was significant, $F(3, 114) = 6.00$, $MSRE = 0.40$, $p < .001$, and accounted for 11.4% of the variance in discrimination score. Three variables remained in this model, and the most influential, as determined by squared semipartial correlation coefficient (Sr^2), was mean localization score ($Sr^2 = 10.5\%$, $p < .001$), followed by the residual difference score ($Sr^2 = 3.2\%$, $p < 0.05$) and the dummy variable taste versus no taste ($Sr^2 = 3.2\%$, $p < .05$). The relationship between discrimination performance and mean localization score was negatively signed (see Fig. 3),

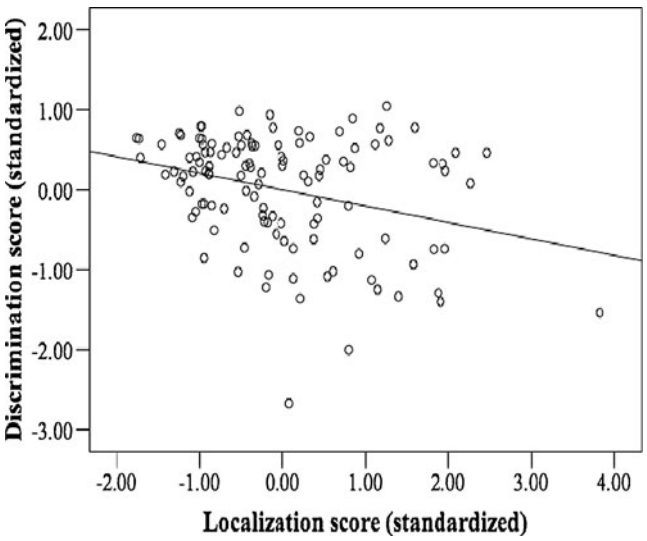


Fig. 3 Partial regression scatter plot (with fitted linear slope) of standardized discrimination score (d') and mean localization score (from discrimination trials)

indicating that greater oral localization was associated with poorer discriminative performance (Sr = −0.32). Similarly, greater disparity in localization within discrimination trials was also independently associated with poorer discriminative performance (Sr = −0.18). The presence of sucrose, however, had the effect of improving discriminative performance (Sr = 0.18).

The regression analysis was then repeated using the oral localization trial score instead of the mean localization score. This analysis (which also had to exclude the same case) was significant, but this time only one variable remained in the model, oral localization trial score (Sr = −0.20, $p < .05$). In sum, greater oral localization was associated with poorer discriminative performance.

Naming Pearson correlations with recognition naming performance revealed significant associations with participant gender, $r(118) = 0.18$, $p = .05$, and with mean localization score, $r(118) = -0.19$, $p < .05$, but only a marginally significant association with oral localization trial score, $r(118) = -0.16$, $p = .078$. The mean localization score on the naming test was highly correlated with localization trial score, $r(118) = 0.85$, $p < .001$, again necessitating separate regression analyses.

Five independent variables—mean localization score, the two dummy variables, age, and gender—were entered simultaneously into regression with backward elimination, with recognition naming performance as the dependent variable. The final model was significant, $F(2, 116) = 4.00$, $MSRE = 2.22$, $p < .025$, and accounted for 4.8% of the variance in recognition naming score. Two variables remained in this model: mean localization score ($Sr^2 = 3.2\%$, $p < .05$) and gender ($Sr^2 = 2.9\%$, $p = .06$). The relationship between recognition naming performance and mean localization score was again negatively signed (see Fig. 4), indicating that greater oral localization was associated with poorer naming (Sr = −0.18). Male gender was also associated with poorer recognition naming performance (Sr = 0.17). The analysis was then repeated using the oral localization score instead of the mean localization score, and this revealed the same significant outcome.

Incidental learning/recognition memory The recognition targets were presented incidentally during the discrimination phase of the experiment, so we established whether the localization variables on the discrimination phase had an impact on performance on the recognition memory test, along with the other variables used for the discrimination and naming analyses (i.e., age, gender, and the two dummy variables). There were no significant correlations between these variables and recognition memory performance, nor with any significant regression model.

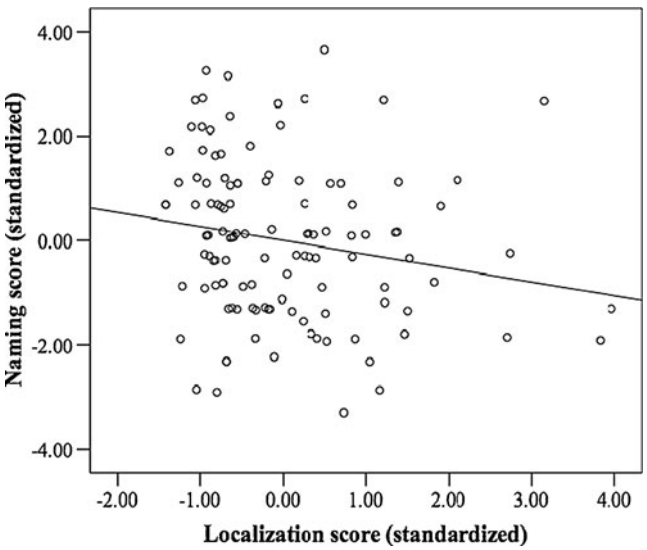


Fig. 4 Partial regression scatter plot (with fitted linear slope) of standardized naming score and mean localization score (from naming trials)

Discussion

In the introduction, we suggested that it might be difficult to attend to odors when they are localized toward or in the mouth. The implications of this statement were tested in the present study in two ways. First, we examined whether manipulating odor localization by mouth condition group would affect olfactory performance for tests sensitive to attention (discrimination, naming) but not for a test insensitive to attention (incidental learning/recognition memory). No differences in olfactory performance were evident here, probably because there was considerable variation in localization response within each group. Second, we capitalized on this variation by treating the localization score as a continuous independent variable, and then examined its relationship to olfactory performance, alongside other relevant variables, using regression. This approach revealed that both discriminative performance and recognition naming were less effective in participants who reported experiencing greater oral localization. However, incidental learning during the discrimination test, as indexed by a later recognition memory test, was independent of localization. In addition, for discrimination, greater average absolute variation in localization within pairs was independently associated with poorer performance, whereas experiencing the odors with sucrose in the mouth was independently associated with improved discriminative ability. For the latter effect, sucrose may have functioned akin to a pedestal, thereby enhancing discrimination of another concurrent stimulus (e.g., Smith, 2000). For odor naming, female gender was associated with better naming

as identified in several previous studies (Brand, 2002; Cain, 1982; Dempsey & Stevenson, 2002). Before considering the implications of these findings, we discuss whether any feature of the design might have affected the observed outcome, whether any other factor associated with reports of oral localization could account for these data, and, more generally, whether our measure of oral localization is valid and reliable.

An ideal design would counterbalance test order; however, this was not possible to achieve in the present study, for two reasons. First, the discrimination test also served as the incidental learning phase for the later recognition memory test, so the discrimination test always had to precede the recognition test, and had to do so by the same time interval and intervening tests (if any). Second, the discrimination test had to precede the naming test, because the naming test inevitably made it more obvious to participants that there were odors involved, which may have acted to weaken any localization effect. In addition, if we had counterbalanced the naming and discrimination tests, this could have led to proactive interference in half of the participants and retroactive interference in the remainder, on the subsequent recognition task, making interpretation of any effect much harder. Given that test order had to be fixed, what effect did this have on the results? One concern is that the failure to find any effect on the recognition task may reflect the fact that it was tested last. However, this is unlikely, because the recognition task was assessing incidental learning that took place on the first task: discrimination. Moreover, if attention did impair incidental learning, then a delay between learning and test would, if anything, exaggerate this impairment, not ameliorate it.

Since the principal findings in the present study rely on a correlation between localization and olfactory performance, it is important to consider whether an unrecognized intervening variable might better account for the observed relationships. One possibility is that there is some person-related variable that both predicts reports of oral localization and poorer naming and discriminative performance. Such a pattern could occur if an oral localization score reflected lower participant motivation or impoverished understanding of the experimental procedures. Accordingly, poorly motivated participants, or those who do not comprehend the tasks, guess on tests of discrimination and naming, and similarly make judgments of "uncertain" (i.e., a score of 4) on the localization task. This would allow for a common pattern to emerge across these three variables.

This account falters for four reasons. First, if localization serves as a proxy for lower motivation or understanding, we would also expect a relationship with recognition memory. Although this might be the case if a participant's understanding of the instructions was at fault, it might not hold for poorly motivated participants, especially if recognition memory judgments were less demanding to make than those for discrimination or naming. Second, we recorded the number of practice trials needed for a participant to reach criterion (i.e., perfect performance of the experimenters' instructions during localization training), yet here there was no correlation between this variable and any of the localization measures (all correlations < .06). Third, the relationship between discrimination and naming and localization trial score was largely the same as to that using the mean localization score, yet the trial score included only participants who definitively reported (i.e., who did not default to an "uncertain" response) oral localization. In fact, if the regression analyses are repeated recoding the localization trial score as a bivariate variable (i.e., showed oral localization on one or more occasion [score of 5+] versus no oral localization shown), the effect sizes are somewhat increased. Fourth, for discrimination, poorer performance was also associated with greater shifts in localization judgments within trial pairs, and it does not seem obvious how one would explain the effect of this variation with reference to participant motivation or understanding.

A further possibility concerns the odor stimuli used on the discrimination trials. As we noted in the introduction, we attempted to minimize differences in the stimulus set between participants by using the same odor sets on each task. However, the "different" and "same" discrimination trials would have varied in content across participants, even though all of these odors were drawn from the same set. This raises the problem of whether harder-to-be-discriminated odors are, for some reason, also those most likely to be localized to the mouth. This possibility looks unlikely, because participants who tended to demonstrate localization on the discrimination task were also those who tended to demonstrate it on the naming trials. In fact, the mean localization score on the naming task was significantly associated with mean discriminative performance, $r(118) = -0.22$, $p < .02$), and mean localization score on the discrimination task was significantly associated with mean naming performance, $r(118) = -0.24$, $p < .01$). This would suggest two things: First, localization judgments made independently from the discrimination trials could still predict performance there, suggesting that differences in the "to-be-discriminated odorants" were not responsible for the localization-discrimination relationship. Second, some individuals are far more prone to oral localization, under our experimental conditions, than others.

A key component of the present study was participants' localization ratings. These judgments reflected whether the participant regarded the odor as more likely to have come from the fluid poured into his or her mouth or from the

puffs received from the squeezy bottle. This measure of localization has been used in a number of studies in varying forms, and it seems to be both a reliable and valid measure of participant's experience of odor localization. We make this claim on the basis of a number of observations. The first concerns the reliability of the procedure. In an earlier study, we found a test–retest correlation of .81 with a 15-min interval (Stevenson, Oaten, & Mahmut, 2010), and in the present study—as was alluded to previously—there were similarly sized correlations between the localization ratings on the discrimination phase and their equivalent on the subsequent naming phase (rs > .78).

Several observations suggest that the procedure is valid, in that it can generate effects similar to those observed when taste and smell are actually presented simultaneously to the mouth as a flavor. The procedure is not simply a consequence of a taste being present, because as the regression analyses demonstrate, localization judgments can affect discrimination and naming independently of the effects of taste. The procedure can detect taste enhancement effects, so that sniffing a sweet-smelling odor with sucrose in the mouth (relative to water) results in greater intensity ratings (Stevenson, Mahmut, & Oaten, 2011). It can also detect the suppressive effect on perceived odor intensity generated by the presence of viscous stimuli in the mouth (Stevenson, Oaten, & Mahmut, 2010)—as a catheterization technique to induce oral localization also can (i.e., Bult, de Wijk, & Hummel, 2007). In addition, in previous studies using a no-oral-stimulus condition, odors were consistently and correctly attributed to the nose (Stevenson, Oaten, & Mahmut, 2010), and both the procedure used here and a straight-out rating of perceived odor location generate similar experimental outcomes (Lim & Johnson, 2011). The new observations reported in the present article suggest that subjective localization judgments may also relate to performance on apparently unrelated tests of olfactory performance. Together, these observations imply that participant reports of an odor's probable source reflect its perceived location and impact on odor perception in a manner comparable to actual flavor perception.

In the introduction, we suggested that one mechanism that may contribute to oral localization is attention. We argued that the capacity to attend to the olfactory channel may be diminished when an odor is perceived to be part of a flavor (i.e., orally located) and hypothesized that this should affect performance on olfactory tasks that require attention. Consistent with this claim, we found that both discriminative performance and recognition naming were less effective when participants reported greater degrees of oral localization. However, for recognition memory, performance was unaffected by degree of oral localization experienced during incidental learning. This difference, relative to naming and discrimination, may reflect two related factors: First, odor encoding may be relatively insensitive to variations in attention (Issanchou et al., 2002). Second, odor and flavor encoding may be similarly efficient, since both have to fulfill important and different biological functions (Stevenson, 2009; Stevenson, 2010). These findings would suggest that tasks analogous to those performed here—but involving actual flavors sampled by mouth, as compared with odors sampled by nose—would yield comparable results, albeit with additional effects generated by the various peripheral factors that influence retronasal perception described in the introduction.

In conclusion, we observed significant associations between the degree of oral localization and performance on an odor discrimination and naming task, but not on incidental learning as indexed by a recognition memory task. This pattern of outcome suggests that attentional processes have a role in generating oral localization—the binding of odor experience to the mouth—and that this process may impair the ability to attend to the olfactory channel.

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References

Ashkenazi, A., & Marks, L. E. (2004). Effect of endogenous attention on detection of weak gustatory and olfactory flavors. *Perception & Psychophysics, 66*, 596–608.

Brand, G. M. (2002). Sex differences in human olfaction: Between evidence and enigma. *The Quarterly Journal of Experimental Psychology, 54B*, 259–270.

Bult, J. H. F., de Wijk, R. A., & Hummel, T. (2007). Investigations on multimodal sensory integration: Texture, taste, and ortho- and retronasal olfactory stimuli in concert. *Neuroscience Letters, 411*, 6–10.

Cain, W. S. (1982). Odor identification by males and females: Prediction vs. performance. *Chemical Senses, 7*, 129–142.

de Araujo, I. E., & Rolls, E. T. (2004). Representation in the human brain of food texture and oral fat. *The Journal of Neuroscience, 24*, 3086–3093.

Degel, J., & Koster, E. P. (1999). Odors: Implicit memory and performance effects. *Chemical Senses, 24*, 317–325.

Dempsey, R. A., & Stevenson, R. J. (2002). Gender differences in the retention of Swahili names for unfamiliar odors. *Chemical Senses, 27*, 681–689.

Frasnelli, J., Heilmann, S., & Hummel, T. (2004). Responsiveness of human nasal mucosa to trigeminal stimuli depends on the site of stimulation. *Neuroscience Letters, 362*, 65–69.

Heilmann, S., & Hummel, T. (2004). A new method for comparing orthonasal and retronasal olfaction. *Behavioral Neuroscience, 118*, 412–419.

Hummel, T., Heilmann, S., Landis, B. N., Reden, B. N., Frasnelli, J., Small, D. M., Gerber, J. (2006). Perceptual differences between chemical stimuli presented through the orth- or retronasal route. *Flavour and Fragrance Journal, 21*, 42–47.

Issanchou, S., Valentin, D., Sulmont, C., Degel, J., & Koster, E. P. (2002). Testing odor memory: Incidental versus intentional learning, implicit versus explicit memory. In C. Rouby, B.

Schaal, D. Dubois, R. Gervais, & A. Holley (Eds.), *Olfaction, taste and cognition* (pp. 211–230). Cambridge: Cambridge University Press.

Lim, J., & Johnson, M. B. (2011). Potential mechanisms of retronasal odor referral to the mouth. *Chemical Senses, 36*, 283–289. doi:10.1093/chemse/bjq125

Rozin, P. (1982). "Taste–smell confusions" and the duality of the olfactory sense. *Perception & Psychophysics, 31*, 397–401.

Scott, J. W., Acevedo, H. P., Sherrill, L., & Phan, M. (2007). Responses of the rat olfactory epithelium to retronasal air flow. *Journal of Neurophysiology, 97*, 1941–1950.

Small, D. M., Gerber, J. C., Mak, Y. E., & Hummel, T. (2005). Differential neural responses evoked by orthonasal versus retronasal odorant perception in humans. *Neuron, 47*, 593–605.

Smith, P. L. (2000). Attention and luminance detection: Effects of cues, masks and pedestals. *Journal of Experimental Psychology. Human Perception and Performance, 26*, 1401–1420.

Spence, C., McGlone, F. P., Kettenmann, B., & Kobal, G. (2001). Attention to olfaction: A psychophysical investigation. *Experimental Brain Research, 138*, 432–437.

Stevenson, R. J. (2009). *The psychology of flavour*. Oxford: Oxford University Press.

Stevenson, R. J. (2010). An initial evaluation of the functions of human olfaction. *Chemical Senses, 35*, 3–20.

Stevenson, R. J., Boakes, R. A., & Wilson, J. P. (2000). Resistance to extinction of conditioned odor perceptions: Evaluative conditioning is not unique. *Journal of Experimental Psychology Leaning, Memory and Cognition, 26*, 423–440.

Stevenson, R. J., Mahmut, K. M., & Oaten, M. J. (2011). The role of attention in the localization of odors to the mouth. *Attention, Perception, & Psychophysics, 73*, 247–258.

Stevenson, R. J., Oaten, M. J., & Mahmut, K. M. (2010). The role of taste and oral somatosensation in olfactory localisation. *The Quarterly Journal of Experimental Psychology, 64*, 224–240.

Tham, W. P., Stevenson, R. J., & Miller, L. A. (2011). *Impaired olfactory attention in participants with mediodorsal thalamic lesions: Effects on oral capture, odor-induced taste synesthesia and flavor binding*. Manuscript submitted for publication.

von Bekesy, G. (1964). Olfactory analogue to directional hearing. *Journal of Applied Physiology, 19*, 363–373.