Chem. Senses 30: 643–649, 2005
doi:10.1093/chemse/bji057
Advance Access publication September 1, 2005

Color Enhances Orthonasal Olfactory Intensity and Reduces Retronasal Olfactory Intensity

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Abstract

The effect of color on orthonasal and retronasal odor intensities was investigated. When odorants were smelled orthonasally (i.e., through the nostrils), color enhanced odor intensity ratings, consistent with previous reports. However, when odorants were smelled retronasally (i.e., the odorous solution was put in the mouth), color reduced odor intensity ratings. These different effects of color on odor intensity (i.e., enhancement orthonasally and suppression retronasally) appear to be the result of route of olfactory stimulation rather than of any procedural artifact. This supports previous reports that retronasal and orthonasal odors are perceived differently.

Key words: multimodal interaction, orthonasal odor, retronasal odor

Introduction

The senses, although generally studied in isolation, do not normally operate independently. Most of our experience is multimodal, and the investigation of the influence of stimulation of one sense on the perception in another has recently got research attention [e.g., Odgaard *et al*., 2003 (white noise increases brightness); Schifferstein and Verlegh, 1996 (odor increases taste intensity)]. One such intermodal effect is the enhancement of odor intensity by color, demonstrated by Zellner and Kautz (1990) and Zellner and Whitten (1999). In these studies, colored odorous solutions were judged as smelling more intense than equally concentrated colorless solutions. One study in Zellner and Kautz used a discrimination paradigm to show that the difference in intensity judgments was due to a perceptual change rather than to a rating response bias. Therefore, subjects do not just give colored solutions higher intensity ratings, they actually perceive them as smelling stronger.

While the effect of color on perceived orthonasal odor intensity (i.e., that perceived when the odor is sniffed through the nostrils) is well established and consistent (i.e., color increases perceived odor intensity), the effect of color on perceived retronasal odor intensity (i.e., that perceived when the odor is in the mouth) has yet to be thoroughly investigated. A recent study (Zellner and Durlach, 2003) found that when subjects drank mint, lemon, and vanilla syrups mixed with water and rated the intensity of the odor component (e.g., mintiness) of these solutions, adding color did not enhance the intensity ratings of the retronasal odor. In fact, the intensity ratings were highest for the clear solutions for all three odorants. It appears that rather than enhancing it, the color suppressed retronasal odor.

A suggestion of a difference in the effect of color on the odor component of foods when smelled orthonasally and retronasally was previously shown by Christensen (1983). She found that color enhanced both the orthonasal and the retronasal odor intensities of a number of foods, but only the orthonasal effect was significant.

That the effect of color on retronasal intensity ratings differs from the effect on orthonasal intensity ratings could be due to perceptual differences in the same odor smelled orthonasally and retronasally. Rozin (1982) proposed that olfaction was a "dual sense" in that olfactory stimuli are perceived differently depending on whether they are detected retronasally or orthonasally. He demonstrated that subjects who were trained to identify soups or juices orthonasally had a difficult time identifying these same soups and juices retronasally. More recently, Heilmann and Hummel (2004) found both physiological and perceptual differences when the same odors in the same concentrations were presented retronasally and orthonasally. In this study, the amplitude of olfactory event-related potentials was smaller, and latencies were more prolonged for retronasal than for orthonasal odors. In addition, olfactory thresholds were higher and intensity ratings were lower for the retronasal odors than for the orthonasal odors. Therefore, perceptions of identical odors via the two routes appear not to be identical.

However, others have found no difference in the identification of odors experienced orthonasally and retronasally (Pierce and Halpern, 1996) and no difference in their detection level (Burdach *et al.*, 1984). Also, functional magnetic resonance imaging (fMRI) activation was similar for retronasal stimulation by odorants in an aqueous solution and odorants presented orthonasally (Cerf-Ducastel and Murphy, 2001).

If different perceptions of the odors presented via the two routes are not causing the difference in the influence of color, maybe it is due to the procedural differences in the studies. Unlike studies showing color-induced orthonasal olfactory enhancement (Zellner and Kautz, 1990; Zellner and Whitten, 1999), the Zellner and Durlach (2003) retronasal odor study had subjects rate refreshment and liking in addition to intensity. Frank *et al.* (1993) found that odorants suppressed sweetness ratings when subjects made multiple ratings, whereas the same odorants enhanced sweetness ratings when only one rating was made. So perhaps the decrease in intensity ratings of the colored solutions in the study of Zellner and Durlach was due to the fact that the subjects were making those multiple ratings. Another difference between Zellner and Durlach and previous studies was that the subjects in the study of Zellner and Durlach rated eight differently colored versions of the solutions, far more than the single color rated in the Zellner and Kautz and in the Zellner and Whitten studies.

The following studies investigate whether there is a difference in the effect of color on the perception of orthonasal and retronasal odor intensities. Experiments 1a and 1b investigate the effect of color on the perception of orthonasal and retronasal odors using identical odors, colors, and procedures in order to eliminate procedural explanations for any observed differences in effects. In addition, they attempt to eliminate any confusion of taste and smell by having the subjects judge the ''fruitiness'' of the solutions rather than the ''odor'' or ''flavor.'' In previous studies where color-induced odor enhancement was seen, subjects judged ''odor intensity'' (Zellner and Kautz, 1990; Zellner and Whitten, 1999). In Zellner and Durlach (2003), where color-induced odor suppression was seen, subjects judged ''flavor intensity'' after being told that what was meant by flavor was the previously identified odor component (e.g., mintiness) and that they should not judge any other qualities such as sweetness or sourness. This difference in what subjects were told to judge could be responsible for the different effects of the color seen in intensity judgments. In Experiments 1a and 1b, subjects made the same judgments when making orthonasal and retronasal odor intensity judgments. Only the route of presentation of the odorant varies, allowing us to determine whether color's effect on odor intensity depends on that variable.

Experiment 1a

In this experiment, subjects judged orthonasal odor intensity by judging the intensity of the fruitiness of colored and colorless water and Glaceau Fruitwater (tangerine–pineapple–guava), which smells very fruity, is not easily identifiable, and has little gustatory component.

Materials and methods

Subjects

Subjects were 15 (13 females and 2 males) volunteer undergraduate psychology students enrolled in higher level psychology courses. Their mean age was 23 years. They were given extra course credit for participation in the study.

Mixtures and materials

All solutions consisted of 10-ml samples in 22.2 cm^3 (PO75 Solo) plastic soufflé cups. The solutions consisted of Great Bear Distilled Water or one of two Glaceau Fruitwaters (cranberry–grapefruit used for the practice trials or tangerine–pineapple–guava used for the test trials). The Glaceau Fruitwaters are flavored unsweetened waters containing distilled, deionized water, natural flavor, and small amounts of citric acid, magnesium lactate, calcium lactate, and potassium phosphate. The Fruitwaters were not sweet, salty, or bitter but did have a barely perceptible sour taste.

The practice solutions consisted of three cups of solutions. The first cup contained half Great Bear Distilled Water and half cranberry–grapefruit Glaceau Fruitwater colored green (0.25 ml McCormick green food coloring/1 l Fruitwater). The second cup was uncolored distilled water. The third cup contained cranberry–grapefruit Glaceau Fruitwater colored green (3 ml McCormick green food coloring/1 l Fruitwater).

The test solutions consisted of three sets of four different types of solutions (for a total of 12 test solutions). Each set of four solutions contained two odorous solutions and two odorless solutions presented in random order. The two odorous solutions were tangerine–pineapple–guava Glaceau Fruitwater. One was colorless, and the other was colored red using McCormick red food coloring (10 ml/1 L Fruitwater). The two odorless solutions were Great Bear Distilled Water. One was colorless, and the other was colored red using McCormick red food coloring (10 ml/1 l water).

Procedures

Subjects were asked to rate the intensity of the odor by judging the intensity of the fruitiness of all solutions using a 101-point scale. The scale was a 23-cm line printed horizontally on a 28 × 21.5–cm sheet of white paper. On the scale, 0 indicated ''no fruitiness,'' 50 indicated ''moderately fruity,'' and 100 indicated ''most intense fruitiness imaginable.'' Subjects were told to rate the intensity of each odor using any number between 0 and 100 by reporting their rating to the experimenter who recorded it.

All solutions were kept behind a partition, out of the view of the subjects. One cup of solution was presented every 30 s for the subject to smell and rate. Subjects smelled the solutions by holding the cup to their noses and sniffing. Cups of solution were returned to the experimenter after each rating.

The three practice solutions were presented first to familiarize the subjects with the procedure. Subjects were told that the first three solutions were practice solutions. After the practice trials, subjects were presented with the three sets of test solutions (a total of 12 solutions) in a randomized block design. During rating of the first two sets, subjects were allowed to view the solutions. During the rating of the third set, subjects were blindfolded. Each set of solutions consisted of four types of solutions. Two solutions in each set were odorous (tangerine–pineapple–guava Glaceau Fruitwater), and two were odorless (Great Bear Distilled Water). One of the odorous solutions was colored red (OC and BOC for the blindfolded), and the other was colorless (O and BO for the blindfolded). One of the odorless solutions was colored red (C and BC for the blindfolded), and the other was colorless (N and BN for the blindfolded).

Results

Ratings from the first two exposures to each of the test solutions were averaged for each subject. Within-subjects t-tests were used to analyze the differences in intensity ratings between the colored and colorless solutions with and without odors (OC compared to O, and C compared to N) and the same pairs of solutions when the subjects were blindfolded (BOC compared to BO, and BC compared to BN).

The colored odorous solution (OC) was rated as being significantly fruitier than the uncolored odorous solution (O), $t(14) = 3.03$, $P < 0.01$. The colored odorless solution (C) was rated as being significantly fruitier than the colorless odorless solution (N), $t(14) = 2.61$, $P < 0.025$ (see Figure 1a).

There was no significant difference in fruitiness ratings between the ratings of the odorous solutions while blindfolded (BOC and BO), $t(14) = 0.15$, $P > 0.85$ or between the ratings of the odorless solutions while blindfolded (BC and BN), $t(14)=1.00$, $P > 0.30$ (see Figure 1a).

Discussion

This study replicated the color-induced odor-enhancement effect seen previously by Zellner and Kautz (1990) and Zellner and Whitten (1999) using slightly different presentation methods for the odorants. Changing the volume of the odor solution samples presented to the subject and the container in which they are presented (cup as opposed to the bottle used in the previous studies) does not appear to alter the effect. In addition, rating the "fruitiness intensity" of the solution rather than the odor intensity (as in the previous studies) did not alter the effect.

In this study, the colored water was judged as being fruitier than the colorless water. This effect is similar to what Engen (1972) reported. In his study, swabs dipped in colored water were judged as having an odor more frequently than were those dipped in colorless water.

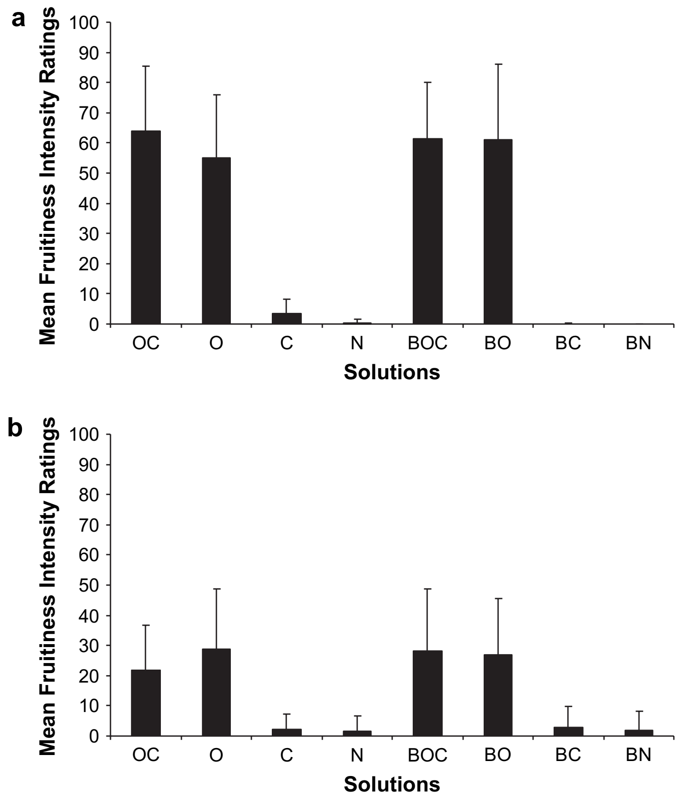

Figure 1 **(a)** Mean orthonasal fruitiness intensity ratings and SDs of OC (odor plus color), O (odor, no color), C (odorless with color), N (no odor or color), BOC (blindfolded judgment of odor plus color), BO (blindfolded judgment of odor, no color), BC (blindfolded judgment of odorless with color), and BN (blindfolded judgment of no odor or color) solutions with a tangerine–pineapple–guava odor in Experiment 1a. **(b)** Mean retronasal fruitiness intensity ratings and SDs of OC (odor plus color), O (odor, no color), C (odorless with color), N (no odor or color), BOC (blindfolded judgment of odor plus color), BO (blindfolded judgment of odor, no color), BC (blindfolded judgment of odorless with color), and BN (blindfolded judgment of no odor or color) solutions with a tangerine–pineapple–guava odor in Experiment 1b.

Experiment 1b

This experiment is a replication of Experiment 1a except that subjects in this study drank the solutions and rated the retronasal, rather than the orthonasal, fruitiness intensity.

Materials and methods

Subjects

Subjects were 15 (12 females and 3 males) volunteer undergraduate psychology students enrolled in higher level psychology courses. Their mean age was 22 years. They were given extra credit for participation in the study.

Mixtures and materials

All solutions were identical to those used in Experiment 1a.

Procedures

The procedure for this study was identical to that for Experiment 1a except that subjects were told to taste the 10-ml contents of each cup of solution by putting the entire contents of the cup in their mouths, swallow the solution, and then give a fruitiness intensity rating. Subjects rinsed their mouths with Great Bear Distilled Water between each cup. Cups were disposed off in a wastebasket located next to the subject, rather than being returned to the experimenter.

Results

Statistical analyses of the data were identical to those of Experiment 1a. The colored odorous solutions (OC) were rated as being significantly less fruity than the colorless odorous solutions (O), $t(14) = 3.00$, $P < 0.01$. There was no significant effect of the color on the fruitiness ratings for the odorless solutions (C and N), $t(14) = 1.45$, $P > 0.15$. Color also had no significant effect when the subjects rated the odorous solutions while being blindfolded (BOC and BO), $t(14) = 0.44$, $P > 0.65$ or when the subjects rated the odorless solutions while being blindfolded (BC and BN), $t(14) = 0.66$, $P > 0.50$ (see Figure 1b).

Discussion

When the odors were presented retronasally, the colored odorous solution was judged as being less fruity than the colorless version as was found by Zellner and Durlach (2003). This is the opposite of the color-enhancement effect found in Experiment 1a when subjects were making the same judgments orthonasally and in previous studies with other odors and colors (Zellner and Kautz, 1990; Zellner and Whitten, 1999).

In fact, a 2 (OC vs. O) × 2 (orthonasal vs. retronasal) mixed analysis of variance comparing the ratings of the odorous solution in Experiments 1a and 1b found a significant interaction, $F(1,28) = 17.96$, $P < 0.001$. This is consistent with the *t*-tests showing that while the color enhanced the odor intensity orthonasally, it suppressed it retronasally. There was also a significant main effect of route (orthonasal or retronasal), $F(1,28) = 24.40$, $P < 0.001$. The subjects in the orthonasal condition (Experiment 1a) rated the odorous solutions as more being fruity than did the subjects in the retronasal condition (Experiment 1b) (see Figure 1a,b). This is similar to the previous findings of Heilmann and Hummel (2004).

Unlike in Experiment 1a, we did not see an effect of color on the odorless solutions smelled retronasally. This was also true of the orthonasal intensity studies in Zellner and Kautz (1990). Therefore, the fact that no effect of color occurred on the odorless solutions here is not necessarily an effect of the retronasal presentation of the odor.

An explanation of the orthonasal color-induced olfactory enhancement effect has been proposed by Zellner and Kautz (1990). They suggested that the color-induced orthonasal odor-enhancement effect might be the result of Pavlovian conditioning. Since colored solutions usually have odors and colorless solutions often do not (the most common odorless solution is water), colored solutions are paired with odor and colorless solutions are not. This might result in the colored solution eliciting a conditioned olfactory percept. This conditioned olfactory percept is sometimes strong enough to be reported as a weak odor when none is present (Engen, 1972, and the present Experiment 1a). However, when the colored solution does have an odor, the conditioned percept adds to the real odor, resulting in a perceived enhancement of the odor (Zellner and Kautz, 1990; Zellner and Whitten, 1999, and the present Experiment 1a).

While the idea of a conditioned olfactory percept being elicited by the colored solution might explain the orthonasal enhancement seen in Experiment 1a, it is not immediately obvious why the sight of the colored solution should also result in retronasal suppression as seen in Experiment 1b. One possibility is that the decrease in odor intensity rating when the solution is in the mouth (retronasal) could be the result of contrast (Pol *et al.*, 1998) between anticipated and experienced retronasal odor intensities. Subjects are experiencing the orthonasal odor of the solutions (as they are lifting the cups to their mouths) prior to experiencing the retronasal odor. This orthonasal stimulation results in an anticipation of how strong the retronasal odor will be. Since color enhances the intensity of orthonasal odors, the orthonasal odor intensity the subjects' experience of the colored odorous solutions would be stronger than that of the colorless solution. This strong orthonasal odor of the colored solution would result in subjects anticipating a stronger retronasal odor experience than when the solution is colorless (and not enhanced by the color orthonasally). This strong intensity expectation when sampling the colored solution would, in turn, result in a weakened perception of the subsequent retronasal odor. This is intensity contrast. Thus, color-induced orthonasal odor enhancement might cause color-induced retronasal odor suppression via sensory contrast.

The following experiment tests this idea. The initial orthonasal stimulation is eliminated by presenting the solution in a lidded cup with a straw. If a contrast effect is causing the retronasal suppression, it should be eliminated by eliminating the orthonasal stimulation.

Experiment 2

This experiment used cups with clear lids and straws to eliminate any effect of orthonasal stimulation prior to retronasal stimulation. Larger cups with lids and a larger volume of solution had to be employed so that subjects could see the color of the solution. A pilot test using these cups without the lids and straws, following the same procedure as Experiment 1b, found the same retronasal suppression, $t(9) = 2.91$, $P < 0.02$.

Materials and methods

Subjects

Subjects were 15 (13 females and 2 males) volunteer undergraduate psychology students. Their mean age was 20 years. They were students enrolled in the introductory level psychology courses and participated as part of the Psychology Department subject pool.

Mixtures and materials

All solutions were identical to those used in the previous experiments, except that 20 ml of solution was put into 266.2-cm^3 (Dart Conex Classic) clear plastic cups, which were sealed with tightly fitting clear plastic lids with a center hole containing a 19.7-cm clear plastic straw.

Procedures

The procedure for this study was identical to that for Experiment 1b except that participants sipped larger volume of the solutions through straws projecting through larger lidded cups rather than drinking the solutions directly from the cups.

Results

Statistical analyses of the data were identical to those of Experiment 1a. The colored odorous solution (OC) was rated as being less fruity than the uncolored odorous solution (O), $t(14) = 2.50$, $P < 0.026$. There was no significant effect of the color on fruitiness judgments of the odorless solutions (C and N), $t(14) = 0.26$, $P > 0.75$. There was also no significant effect of color when the subjects rated the odorous solutions while being blindfolded (BOC and BO), $t(14) = 0.72$, $P > 0.50$ or when the subjects rated the odorless solutions while being blindfolded (BC and BN), $t(14) = 1.00$, $P > 0.30$ (see Figure 2).

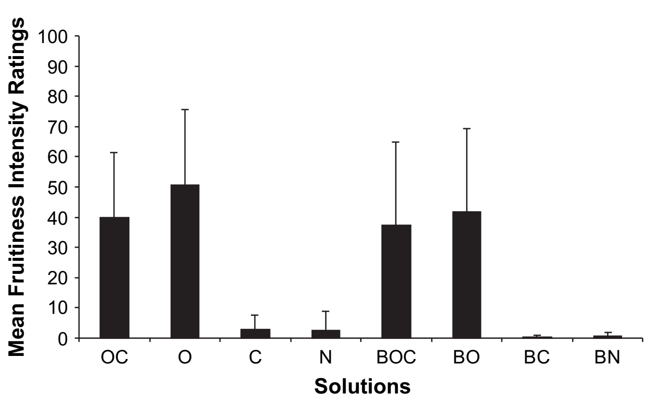

Figure 2 Mean retronasal fruitiness intensity ratings and SDs of OC (odor plus color), O (odor, no color), C (odorless with color), N (no odor or color), BOC (blindfolded judgment of odor plus color), BO (blindfolded judgment of odor, no color), BC (blindfolded judgment of odorless with color), and BN (blindfolded judgment of no odor or color) solutions with a tangerine–pineapple–guava odor presented in a lidded cup with a straw in Experiment 2.

Discussion

Orthonasal stimulation preceding retronasal stimulation is not responsible for the suppression of retronasal odor intensity by color.

General discussion

Experiment 1b is the first demonstration of a color-induced olfactory suppressant effect with retronasal olfaction under conditions equivalent to those used when color-induced orthonasal odor enhancement is seen (Experiment 1a). Experiment 2 demonstrated that the effect still occurs when orthonasal stimulation preceding retronasal stimulation is eliminated. This demonstrates that the effect is not the result of intensity contrast caused by the initial orthonasal stimulation but is the result of the route the odorant takes to the olfactory mucosa.

This result supports Rozin's (1982) idea that olfaction is a dual sense and that an odor in the mouth is perceived differently from an odor from the external environment. The present findings and those of Rozin and others suggest that retronasal and orthonasal inputs are processed differently past the level of the receptor. For example, Rankin and Marks (2000) found that an orthonasal odor (vanilla or orange) was judged to be as different from that same odor presented retronasally as it was from sipped sucrose (a gustatory stimulus). They went on to show that sucrose taste and retronasal orange odor influence each other's ratings (context effects) more than do orthonasal and retronasal orange odors. So, not only is a retronasal olfactory stimulus judged as being more like sucrose (a gustatory stimulus) than like itself presented orthonasally but also judgments of its intensity are more affected by sucrose than by itself presented orthonasally.

Sensory cues, such as the path of the airflow carrying the odor molecules over the olfactory epithelium, the tactile information from the mouth, and/or swallowing or sniffing, might signal the brain that a particular odor is the result of environmental or mouth stimulation. Even higher level cognitive cues might signal the brain that the odor is ''out there'' or ''in here'' and result in processing the odor differently. Certainly, higher level cues affect both the intensity and pleasantness of odors (Moskowitz, 1979; Zellner *et al.*, 1991; Distel and Hudson, 2001; Herz and von Clef, 2001; Herz, 2003). Therefore, knowing that something is coming from your mouth or the external environment might well alter the perception of its odor. If the sensory signal is ''tagged'' one way from the mouth and another way from the nose, the visual input about the color of the solution could influence those two tagged signals in different ways (enhancing one and suppressing the other).

Because the mouth is the guardian of the body, stimuli within the mouth should be much more salient than those coming from the environment. Rozin *et al.* (1995) found that an objectionable food is rated as much more objectionable when it is in the mouth, particularly when touching the tongue, than when it is outside of the mouth. We pay attention to stimuli in our mouth because at that point the decision has to be made whether to incorporate that substance into the body. If subjects are paying more attention to the stimuli coming from their mouths (retronasal odor) than to those coming from the environment (orthonasal odor), they should more readily notice any discrepancy between the stimulus they experience and what they expect when the stimulus is in their mouths.

For affective judgments, noticing a discrepancy between what is expected and what is experienced has been found to produce contrast, whereas assimilation occurs when the discrepancy is not noticed (Wilson *et al*. 1989; Wilson and Klaaren, 1992). Possibly, the same type of phenomenon is occurring here with intensity judgments. In both the orthonasal and retronasal conditions, subjects should expect the colored solution to have a stronger odor than the colorless solutions. Since the two solutions are equally intense, there will be a discrepancy between what is expected and experienced. In the retronasal condition this discrepancy might be noticed because of the saliency of the stimulus in the mouth. This will result in, contrast, a lower intensity rating for the colored solution than for the colorless solution. The same discrepancy might not be noticed in the orthonasal condition because the stimulus is less salient, coming from the environment, or because the addition of a conditioned olfactory percept increases the perceived intensity of the colored solution. In either case, a higher intensity rating for the colored solution than for the colorless solution will occur through assimilation or the addition of the conditioned olfactory percept.

Since many studies (e.g., Rozin, 1982; Burdach *et al*., 1984; Rankin and Marks, 2000; Cerf-Ducastel and Murphy, 2001) looking at retronasal olfaction involve subjects swallowing a stimulus, it is likely that they are also receiving some gustatory stimulation. This stimulation might be important in signaling that the odor that is being experienced is coming from the mouth. In addition, it could be influencing the perception of the odor. In the present study, we used a stimulus with a gustatory component (sour), which only about half the people could detect. While unlikely, it is possible that since the flavored water that was used in the present studies was not totally tasteless, the suppression induced by the color in the retronasal condition might be the result of some effect of the color on the gustatory component of the stimulus. Subjects could have been combining gustatory intensity ratings with the olfactory intensity ratings in the retronasal condition since taste and smell are confused (Rozin, 1982). Red coloring has been found to increase the perceived sweetness of sucrose-sweetened solutions in some (Johnson and Clydesdale, 1982; Johnson *et al*. 1982, 1983) but not all (Frank *et al*. 1989) studies. We know of no studies showing an increase in sweetness of solutions not already sweetened. If the effect we are seeing is really an effect of color on taste, we would expect it to increase the sweetness of the colored solutions, which might cause an increase in fruitiness ratings. This should have been particularly true in Zellner and Durlach (2003) when sweetened solutions were employed and subjects were judging the flavor of the solutions. However, that study found a decrease rather than an increase in fruitiness ratings of the colored solution. We think it even more unlikely that the color-induced suppressant effect is the result of color's effect on gustation in the present Experiments 1b and 2, where the solutions had only a barely perceptible sour taste to some subjects. In a previous research (Maga, 1974), red coloring was found to have no effect on sour thresholds. However, the possible influence of taste on this effect should be investigated further in future studies.

Since most of our olfactory experience occurs in a multimodal setting, both retronasally when we eat and orthonasally as we smell things in our environment, these other sensory inputs are altering our olfactory experiences quantitatively (as shown in this study) and perhaps even qualitatively. The present studies demonstrate that how these other sensory modalities, specifically vision, influence perception of an odor depends on the route of administration of that odor.

Acknowledgements

We thank Scott Parker and two anonymous reviewers for their helpful comments on the manuscript and Julian Keenan, Yoav Arieh, and Cigdem Talgar for their technical assistance. We also thank Christy Cheatham and Melissa Edwards for work on pilot studies.

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Accepted August 11, 2005