Crossmodal interaction of color and smell

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Psychophysical experiments have shown that color can have a profound effect on odor perception. We have used fMRI to investigate the neural correlates of this multisensory influence. An initial behavioral experiment determined appropriate color-smell smell combinations, which were strawberry-red, lemon-yellow, caramel-brown and spearmint–turquoise. During the fMRI experiment, colors or smells were presented either alone or in a matching or mismatching combination. Modulation of the response to odor alone by the presence of a matched or mismatched color was observed in the orbitofrontal cortex, the cingulate and the insular gyrus. These data indicate that crossmodal influences of color on odor perception are mediated in polysensory areas mainly in the orbitofrontal region of the brain.

Introduction

Odors are often perceived together with visual cues, which interact and modulate our subjective experience of the stimuli from which they emanate. One visual feature that seems to have a particularly strong influence on our perception of odors is color. For example, people are more likely to perceive an odorless solution as odorized if it is colored (*1*). Color has also been shown to influence judgements of odor intensity and pleasantness. For example, both the perceived intensity and pleasantness of an appropriately colored solution (e.g. red-strawberry) is judged higher than that of an inappropriately colored (e.g. green-strawberry) or a colorless solution even if the actual concentration of odorant remained equal (*2*).

Areas of visual and olfactory convergence in mammals have been found in the piriform cortex, the olfactory tubercle, the cortical region of the medial amygdala and the lateral hypothalamus (*3*). Bimodal neurons responsive both to visual and olfactory stimulation have been reported within the orbitofrontal cortex of non-human primates (*4*).

Here we use functional magnetic resonance imaging (fMRI) to (i) identify brain areas involved in integrating colors and odors and (ii) the mechanisms by which matching or mismatching colors can influence odor perception.

Methods

8 right-handed volunteers participated in the fMRI study (5 females and 3 males; mean age 28 years, age range 22-35 years).

Subjects were presented for 6s with either a visual stimulus, an olfactory stimulus or both simultaneously in random order. Each presentation was followed by a rest period of 30s. The olfactory stimuli were lemon, strawberry, spearmint and caramel (Quest Intl.,UK) and the visual stimuli yellow, red, turquoise and brown. These four odors were most reliably matched to colors in a behavioral experiment prior to scanning.

For the unimodal conditions, each of the 4 olfactory and visual stimuli was presented 3 times. For the bimodal conditions, each odor was presented 3 times with an appropriate color and once with each of the remaining 3 colors. Overall, 12 visual, 12 olfactory and 24 bimodal stimuli were presented over a period of 28 min 48s.

The task during the scanning session was to rate each color-smell combination with respect to 'goodness of fit between color and smell' on a rating scale ranging from 1=very good to 4=very bad. Subjects were indicating their rating by pressing one of 4 buttons.

Functional and morphological MRI images were acquired on a Varian/Siemens 3-Tesla imaging system. For the functional data series, a total of 581 T2* weighted EPI volumes depicting BOLD contrast were taken. Each volume consisted of 25 continuous coronal slices with an in-plane resolution of 3x2.5mm and a thickness of 3mm, covering the anterior half of the brain (TR=3s, 64x64 Matrix, FOV 192x160 mm, TE=60ms, Flip angle 90°). Analysis was carried out using FEAT (FMRIB). Data was motion corrected using MCFLIRT (*5*) and spatially smoothed with FWHM 5mm. Each of the 3 event types (visual, olfactory and bimodal) was modeled as a separate explanatory variable. A fourth explanatory variable was used to model the linear interaction between bimodal presentations and the degree of matching. Statistical analysis was carried out using FILM (FMRIB's Improved Linear Model) (*6*) and statistic images were thresholded using clusters determined by $Z>1.7$ and a cluster significance threshold of $P=0.01$.

Results

Appropriate color-smell combinations were rated as better matching than combinations of the same odor with each of the other 3 colors. Mean ratings for the various odor-color combinations averaged across all subjects were: lemon-yellow = 1.08 (SD=0.28), lemon-other = 2.88 (SD = 0.85), spearmint-turquoise = 1.38 (SD = 0.88), spearmint-other = 3.08 (SD = 1.06), caramel–brown = 1.96 (SD = 0.91), caramel-other = 3.39 (SD = 0.89), strawberry-red = 2.17 (SD = 1.03) and strawberry-other = 2.67 (SD = 0.91).

Figure 1 shows areas of brain for the group that responded in a graded fashion according to the degree of congruency between various odor-color combinations and Fig.2 the average BOLD effect across the entire network for all subjects.

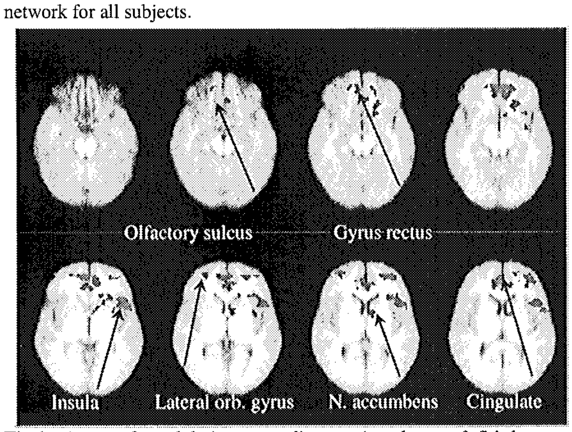

Fig.1: Areas of modulation according to 'goodness of fit' between various color-odor combinations. The right side of the brain is shown on the left side of the picture

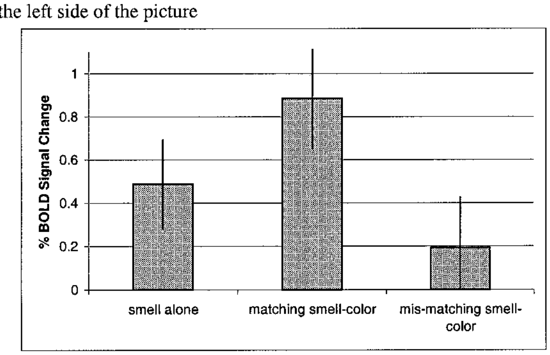

Fig.2: Percentage BOLD signal change in the experimental conditions averaged across all 8 participants. Black lines show standard error.

Conclusions

These findings suggest that color and olfactory cues converge and interact in the human orbitofrontal cortex. Specifically, matching odor-color combinations enhance activity in olfactory processing areas, mis-matching combinations suppress activity below that observed to odors alone. Together, these findings provide a neurophysiological basis for behavioral effects such as the change in the perception of white wine's odor when artificially colored red (*7*).

References

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