

Olfactory fMRI of Human Brain: Emotional and Other Brain System Responses to Different Odors

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Abstract The human olfactory system is known to be closely linked to emotions and moods. Brain responses to two odors (lavender and peppermint) that are known to generate distinct mood attributes were studied on eight normal young adults with an average Smell Identification Score of 37.4. Both lavender and peppermint elicited different profiles of neural reactivity, indicating that olfactory stimuli can have profound effects on sensory, motor and emotion-processing systems.

Introduction The effects of smells on human behavior and performance are likely mediated by the emotional response and mood states that are stimulated by odors. Thus, olfactory fMRI activation maps in the brain may provide a marker to characterize and differentiate the neural patterns of activity leading to specific responses. To study how this process is executed in the human brain, we focus this project on the brain responses to the odors that generate mood known attributes. Although functional MRI has been used to investigate human brain activity related to olfactory stimulation for over seven years[1-4], most of the work has been concentrated on a localized region (such as primary olfactory areas) in the brain. This study has extended the observation of the brain responses to different odors to multiple brain regions with fMRI.

Methods Eight normal non-smoking adults (average age 26 years old, range from 22 to 41, 2 male and 6 female, 7 right-handed and 1 left-handed, educational levels college or above) participated in the study. There were no history of medical, psychiatric or rhinal conditions and test scores of the University of Pennsylvania Smell Identification Test [5] were within normal limits (average score 37.4±2.0). The two odors used for the study were lavender (relaxing) diluted in 10% PPG and peppermint (invigorating) in 10% PPG (provided by Quest International). Following the procedures of Van Toller S. et al. [6], subjects provided subjective ratings of the odorants after fMRI study. These psychometric judges were quantified with a 0-10 Likert scale for the following 3 dimensions: familiarity, preference, and smell intensity. Each subject received olfactory functional MR imaging twice with each odor with a 15-minute interval in between. During MRI, fresh air with a flow rate of 8L/Min was delivered to both nostrils of the subject. The olfactory fMRI paradigm consisted of five cycles of 45 s resting (16 images) and 11.2 s stimulation (4 images). The timing and switching of the odorants' delivery were automatically controlled by TTL signals incorporated in the pulse-timing program. This paradigm only required the subjects' attention to the odorants delivered to their noses. The subjects were instructed and trained to breathe normally without sniffing during the study cycle. Olfactory fMRI studies were carried out on a 3.0T human imaging system (MEDSPEC S300, Bruker Instruments, Inc., Karlsruhe, Germany). For the fMRI data acquisition, 110 EPI (TR/TE/FA = 2800ms/35ms/90°, FOV = 250 × 250mm², matrix = 128 × 96, 20 axial slices, slice thickness = 5mm) image sets were acquired during the execution of the olfactory paradigm. The fMRI image data were processed with SPM99 [7]. Statistical parametric maps of each group were created after one-sample *t*-test ($p < 0.001$, Figures 1 and 2). Two groups of SPMs from all the subjects were processed with two-sample *t*-test ($p < 0.01$) to obtain the difference activation map.

Results Both lavender and peppermint elicited patterns of widespread brain activation involving mainly frontal, temporal, insula, and parietal cortices (Figures 1 and 2) which mediate emotion, attention, sensorimotor and cognitive processes. Primary olfactory areas of frontal and temporal prepiriform cortices were activated including the uncus. Subcortical activations were detected in the cerebellum, amygdala, brain stem, and thalamus (the latter likely involving the reticular activating system). Despite these similarities, several differences were also identified. Statistical comparisons indicated that peppermint stimulation caused more widespread activation than lavender. A greater focus of brain activity was also detected in the regions of the insula and premotor cortex, suggesting more emotional reactivity and motor preparedness. Subjects consistently rated peppermint as refreshing and even invigorating. In contrast, lavender elicited greater activation of somatosensory and

inferior temporal cortices, suggesting more somatic and visual reactivity, possibly imagery-based. Subjects rated lavender as calming, warm and refreshing.

Discussion & Conclusion Current neuroscience models of emotion suggest that there can be rapid, automatic activation of emotions, represented through somatic, visceral-autonomic, attentional and motor-related changes. These reactions are a combination of innate and learned responses that may bias elicited representations from various stimuli and prepare body as well as cognitive systems for more detailed processing and action. Though brain activation patterns were similar in certain respects, lavender and peppermint also elicited different profiles of neural reactivity, indicating that olfactory stimuli can have diverse and profound effects on emotion-processing, sensory, motor and cognitive systems.

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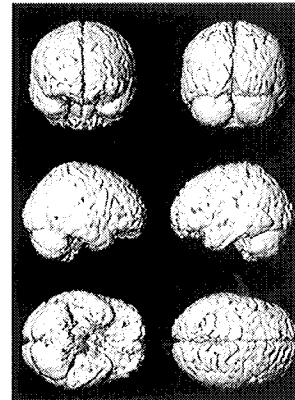


Figure 1. Lavender stimulated SPM from 8 normal subjects overlaid on normalized human brain

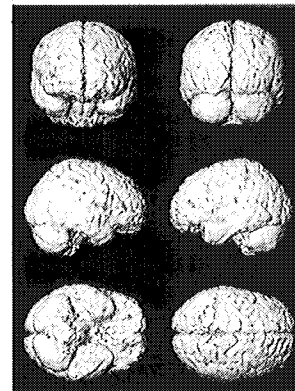


Figure 2. Peppermint stimulated SPM from the same 8 normal subjects overlaid on normalized human brain