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THE FATE OF THE INNER NOSE: ODOR IMAGERY IN PATIENTS WITH OLFACTORY LOSS

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Abstract—Cerebral activations during olfactory mental imagery are fairly well investigated in healthy participants but little attention has been given to olfactory imagery in patients with olfactory loss. To explore whether olfactory loss leads to deficits in olfactory imagery, neural responses using functional magnetic resonance imaging (fMRI) and self-report measures were investigated in 16 participants with acquired olfactory loss and 19 control participants. Participants imagined both pleasant and unpleasant odors and their visual representations. Patients reported less vivid olfactory but not visual images than controls. Results from neuroimaging revealed that activation patterns differed between patients and controls. While the control group showed stronger activation in olfactory brain regions for unpleasant compared to pleasant odors, the patient group did not. Also, activation in critical areas for olfactory imagery was correlated with the duration of olfactory dysfunction, indicating that the longer the duration of dysfunction, the more the attentional resources were employed. This indicates that participants with olfactory loss have difficulties to perform olfactory imagery in the conventional way. Regular exposure to olfactory information may be necessary to maintain an olfactory imagery capacity.

Key words: olfactory loss, functional magnetic resonance imaging, mental imagery, olfaction, vividness.

INTRODUCTION

Mental imagery is defined as the ability to retrieve and experience perceptual information from memory (Kosslyn et al., 2001). Studies show that the neural mechanisms of mental imagery to some extent are modality specific and overlap with those seen during normal perception (e.g., Farah et al., 1988b; Kosslyn et al., 2001). This overlap has been demonstrated for a range of sensory modalities, including the visual (Kosslyn et al., 2001), auditory (McNorgan, 2012) as well as the olfactory system (Djordjevic et al., 2005). Moreover, studies show that lesions in sensory-specific brain regions give rise to modality-specific impairments in both perception and imagery. This has been shown for both the visual (Farah et al., 1988a, 1992) and the auditory system (Zatorre and Halpern, 1993) but evidence is scarce regarding the impact of sensory impairments on olfactory imagery.

Although most studies favor the notion of a capacity to form olfactory images the ability is still under debate (for a review, see Stevenson and Case, 2005). Nevertheless, evidence for the existence of olfactory imagery comes from a range of studies including psychophysical (e.g., Djordjevic et al., 2004), cognitive (e.g., Lyman and McDaniel, 1990), and neuroimaging studies (e.g., Djordjevic et al., 2005; Bensafi et al., 2007). Among the first studies targeting the neural correlates of olfactory imagery was a positron emission tomography (PET) study conducted by Djordjevic et al. (2005). The authors showed that key regions activated during olfactory perception such as piriform cortex (Pir), orbitofrontal cortex (OFC), and insula also were activated during olfactory imagery. Their observation was taken as evidence of an olfactory imagery capacity in humans, although it is important to note that a number of factors that are normally present during olfactory imagery, such as sniffing (Sobel et al., 1998a; Bensafi et al., 2003), attentional demands (Geisler and Murphy, 2000; Zelano et al., 2004; deAraujo et al., 2005), and semantic information (González et al., 2006) independently may activate olfactory brain regions (i.e., Pir, OFC, and insula). Hence, caution is warranted when activations in olfactory regions are attributed to the olfactory image per se (see Royet et al., 2013 for a review). To address such potential biases, Bensafi et al. (2007) studied olfactory imagery as a function of the hedonics of the odor to be imagined. Neuroimaging studies of olfactory perception have shown that unpleasant odors activate olfactory brain regions differently with selectively higher

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Abbreviations: ANOVA, analysis of variance; CG, control group; DLPFC, dorsolateral prefrontal cortex; fMRI, functional magnetic resonance imaging; MNI, Montreal Neurological Institute; OFC, orbitofrontal cortex; OI, olfactory imagery; OLG, olfactory loss group; Pir, piriform cortex; TDI, threshold discrimination identification; TE, echo time; TR, repetition time; VI, visual imagery; VOIQ, Vividness of Olfactory Imagery Questionnaire.

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activations in the insula as compared to pleasant olfactory information (Gottfried et al., 2002; Heining et al., 2003; Royet et al., 2003). Bensafi et al. (2007) argued that if similar neural activations would emerge during olfactory imagery of pleasant and unpleasant odors the activations could not be attributed to confounding factors (e.g., sniffing and attentional demands) as long as these factors would be held constant between odors. The results showed that activations following imagery mimicked the perceived hedonics of the odorant being imagined, with stronger activations in the left piriform cortex and insula.

While behavioral and neural correlates of olfactory imagery have been studied in multiple aspects, knowledge regarding olfactory imagery functions in patients with olfactory loss is scarce. The effects of perceptual loss on mental imagery have been extensively explored in the visual modality. For example, (Dulin et al., 2011) demonstrated that visual loss had a negative impact on visual imagery. They argued that a memory of an image was not fully retrieved without visual input and that visual perceptual practice was a necessary factor to maintain a visual imagery capacity. Moreover, the results demonstrated that the negative effect of visual disorders partially could be compensated for by attentional processes (e.g., working memory), and that the importance of attentional resources during visual imagery increased with visual deficiencies. To date, two studies have been conducted focusing on olfactory imagery in patients with olfactory loss. Both used patients with hyposmia (Levy et al., 1999; Henkin and Levy, 2002) and reported an increased activation in olfactory regions following olfactory imagery. The activations were interpreted as a sign of preserved olfactory imagery capacity in patients with acquired olfactory loss. However, both studies suffered from methodological problems with few participants (*n* = 3) in the experimental condition (Levy et al., 1999) and no control group (Henkin and Levy, 2002). Also, none of the studies controlled for the potential confounds described above.

Thus, little is known regarding the relationship between perceptual integrity and olfactory imagery capacity. The examination of olfactory mental imagery in acquired olfactory loss is important to further investigate this relationship. Given the assumption that mental imagery relates to perception in a modality-specific manner, it may be hypothesized that olfactory loss would have an impact on olfactory imagery that does not generalize to imagery in other modalities. An adapted version of the paradigm used by Bensafi et al. (2007) while controlling for potential confounds (i.e., sniffing) was used. Control participants who scored high in olfactory proficiency and patients with acquired olfactory loss were exposed to pleasant and unpleasant odor labels in the MRI scanner and were instructed to imagine the respective odor. Variations in activation patterns in olfactory regions as a function of the hedonics of the imagined odors would indicate an intact olfactory imagery capacity among patients (cf., Bensafi et al., 2007). As activation patterns following visual imagery should not differ with the hedonics of the imagined picture a visual imagery task was used as control condition. We hypothesized that similar to patients with visual loss in the study by Dulin et al. (2011), patients with olfactory loss would, due to the lack of practice, show a lower level of olfactory imagery capacity than control participants. Moreover, we hypothesized that this difference would be reflected in similar brain activity as reported by Plailly et al. (2012) who demonstrated that the individual capacity to form olfactory images was a direct function of the amount of olfactory imagery training. Specifically, they showed that perfumers exhibited a lower level of activation in olfactory areas as compared to non-experts. Also, increased expertise (defined as duration of work experience) modified neural activity such as longer work experience was related to less brain activity in areas associated with olfactory imagery. This type of experience-dependent decrease in modality-specific neural activity has been reported across several modalities (e.g. auditory: Lotze et al., 2003; motoric: Ross et al., 2003). Hence, we hypothesized that the duration of the smell loss would be correlated with activation in olfactory areas. Also, we hypothesized that patients would allocate more attentional resources by recruiting areas associated with working memory to a higher extent than controls (Dulin et al., 2011).

EXPERIMENTAL PROCEDURES

Participants

Forty-six participants (23 in each group) took part in the study. After the exclusion of 11 participants (see below), 35 participants (16 patients with severe olfactory loss and 19 control participants with high smelling capacities) were included into the analysis. The olfactory loss group (OLG) was recruited among patients at the Smell and Taste Clinic at the Department of Otorhinolaryngology of the Technical University of Dresden. The control group (CG) was recruited via advertisements in nearby fitness centers. The OLG consisted of 5 men and 11 women (mean age 53.8 years, ranging from 21 to 77 years). The CG consisted of 8 men and 11 women (mean age 54.9 years, ranging from 40 to 74 years). Sex distribution ($X^2_1 = 0.44$, $p = .51$), educational background ($X^2_3 = 4.78$, $p = .19$), and age ($t_{33} = 0.24$, $p = .81$) did not differ between the groups.

Patients reported the suspected causes for the smell loss at the beginning of the experiment. Diagnoses in 10 participants were trauma, in one acute viral infection of the upper respiratory tract and in 5 participants, causes were unclear (idiopathic olfactory loss).

Olfactory function was assessed using the ‘‘Sniffin’ Sticks’’ test (Hummel et al., 1997), yielding TDI (i.e., ‘‘Threshold, Discrimination, and Identification’’) scores. Smell ability differed between the two groups ($t_{33} = 14.132$, $p < .001$). The OLG reached an average TDI score of 13.39 (ranging from 10 to 20.5), the CG a TDI score of 32.95 (ranging from 26.25 to 43). Exclusion criteria for both groups were olfactory dysfunction due to neurological diseases (such as Parkinson’s disease),