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DIFFERENCES IN THE CENTRAL-NERVOUS PROCESSING OF OLFACTORY STIMULI ACCORDING TO THEIR HEDONIC AND AROUSAL CHARACTERISTICS

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Abstract—Given the strong relationship between human olfaction and emotion, it is not surprising that numerous studies have investigated human response to hedonic and arousing qualities of odors. However, neuropsychological research addressed rather the pleasant–unpleasant, and not the arousing–calming dimension of emotional states generated by odorants. The purpose of the presented fMRI study was to evaluate the differences in cerebral processing of olfactory stimuli, focusing on both of these dimensions of emotional experiences, i.e., pleasantness and arousal. We investigated the patterns of activation generated by odors differing in hedonic tone and generated arousal while controlling the stimuli intensity. This design allowed for a new insight to the emotional odor processing with imaging techniques. The pleasantness was related to activation in the cingulate gyrus, the insula, the hippocampal area, the amygdala, and the superior temporal gyrus, whereas arousal affected activation in the thalamic relay. The present study showed also that the emotional states generated by arousing qualities of odorants are an important determinant of magnitude of cerebral activation.

Key words: smell, olfaction, pleasantness, arousal, intensity, fMRI.

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Abbreviations: IBA, isobornylacetate; MTG, middle temporal gyrus; STG, superior temporal gyrus; TE, echo time; TR, repetition time.

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INTRODUCTION

Odors are known for their ability to evoke strong sensations of pleasure or displeasure (Ehrlichmann and Bastone, 1992). Many studies postulate the influence of olfaction on emotions, mood and behavior (Baron, 1981; Royet et al., 2000; Holland et al., 2005; Sakamoto et al., 2005), and the reverse, presence of olfactory dysfunctions in mood disturbances (Croy et al., 2014). The strong relation between olfaction and emotion results from overlapping cerebral processing structures belonging to the limbic system – it is thus found in subcortical structures, before the modulatory influence of higher degree cortical brain regions (Ehrlichmann and Bastone, 1992).

Valence and arousal are thought to be the principal determinants of approach/avoidance behaviors, in the sense of basic motivational parameters (Lang et al., 1992), and models like the Circumplex Model of Affect (Posner et al., 2005) propose that the main variance of emotional meaning is determined by two factors: pleasure and arousal (Russell, 1980; Lang et al., 1993; Posner et al., 2005). Consequently, each emotion can be defined within a coordinate space along the independent valence and arousal dimensions (Posner et al., 2005). Given the strong relationship between olfaction and emotion, it is not surprising that numerous studies have investigated associations between human behavior, cognition and hedonicity and arousing qualities of various aromas. However, the neuropsychological studies related to odors and emotions have focused mostly on valence of odorants. Various aspects of odor pleasantness of odors have been investigated in studies involving EEG, fMRI and PET (e.g., Hummel et al., 1989; Royet et al., 2000, 2001, 2003; Anderson et al., 2003; Rolls et al., 2003). Still, little is known about the processing of olfactory stimuli with regard to their arousing/calming qualities. Only a few neuropsychological studies have analyzed the cerebral processing of odor intensity (as a surrogate for arousal) while controlling for odor valence (Anderson et al., 2003; Winston et al., 2005). Anderson and collaborators (2003) observed that amygdala activation was associated with intensity, and not valence, of odors, and Winston and colleagues (2005) further concluded that the amygdala response was observed for pleasant and unpleasant smells but not for neutral odors. It needs to be noted, however, that although odor intensity correlates with indices of generated arousal (Bensafi et al., 2002a), results from other sensory modalities suggest that stimulus intensity is not necessarily equivalent with its arousing qualities

(Jönsson et al., 2015). Consequently, based on existing neuropsychological studies it is rather hard to present any definite conclusions about cerebral processing of two dimensions of emotional states generated by odorants.

In summary, further neurophysiological research on olfaction and emotions is still necessary. Clear lines are difficult to define, because previous designs have rather focused on odor pleasantness alone, or involved smell intensity as a proxy of arousing qualities of applied odorants. The purpose of the presented fMRI study was to evaluate the differences in cerebral processing of olfactory stimuli matched in intensity, focusing on the both dimensions determining the emotional experiences.

EXPERIMENTAL PROCEDURES

Participants

Women are often found to outperform men in terms of olfactory abilities (for a review see: Doty and Cameron, 2009). Although some studies did not find the gender effect on olfactory performance (Hummel et al., 2001; Sorokowska et al., 2015), to avoid possible interpretation difficulties we decided to include only females in the study. A total number of 18 females aged between 19 and 30 were enrolled ($M = 22.71$).

Subjects were recruited by ads placed inside the hospital area of the TU Dresden; they received monetary remuneration for their participation. The study design was approved by the Ethics Committee of the Medical Faculty at the TU Dresden. All participants provided written informed consent prior to their inclusion to the study. The whole procedure consisted of two sessions – an introductory session and an fMRI experiment.

During the introductory session, participants were asked to fill in a detailed medical questionnaire regarding their health status and underwent a complete ENT examination. The olfactory function of each participant was assessed using the Sniffin' Sticks test kit (combined score for measures for odor threshold (T), olfactory quality discrimination (D) and odor identification (I); Hummel et al., 1997, 2007). Only healthy and normosmic subjects were included to participate in the further fMRI experiment. Other exclusion criteria were age under 18 years, history of severe neurological of medical comorbidity, head trauma, substance abuse, heavy smoking or drinking, history of any disease known to have an impact on olfactory function (Landis et al., 2004). All subjects were right-handed as determined with a translated version of the Edinburgh Handedness Inventory (Oldfield, 1971). Subjects also completed an MRI exclusion criteria inventory for the participation in the second experiment. Only subjects who fulfilled none of following exclusion criteria were enrolled: pregnancy, claustrophobia, ferromagnetic foreign bodies and metallic implanted devices (pacemakers, mechanical heart valves, aneurysm clips, implantable cardioverter-defibrillators, loop recorders, insulin pumps, deep brain stimulators, metallic prosthesis, cochlear implants, intra uterine devices, etc.).

Odorants

Our design involved a group of preselected odorants differing in hedonic tone and generated arousal. First, 12 different odorants were selected by a group of perfumers who classified the samples as pleasant/unpleasant and arousing/calming. Further, the authors of the study and other Smell and Taste Clinic lab members individually categorized each odor as arousing-pleasant, arousing-unpleasant, calming-unpleasant or calming-pleasant. We found no odorants to be unpleasant and calming, however this was consistent with the perfumers' opinions and literature suggesting that unpleasant odorants are rather arousing (Bensafi et al., 2002a,b; Royet et al., 2003), and that negative stimuli are typically more arousing than positive stimuli (Carretié et al., 2001; Anderson et al., 2003). The 6 odors that were classified unanimously to certain groups were included in the fMRI project (group A: "pleasant and arousing"; group B: "pleasant and calming"; group C: "unpleasant and arousing"); Thesaron (fresh, fruity odor; CAS number 22471-55-2) and isobornylacetate (IBA; smell of pine needles) constituted the "pleasant and arousing" group, vanillin and rose ("Rose Absolute" from Morocco) were part of the "pleasant and calming" group, while chamomile ("Chamomile Blue Essential Oil" from Egypt) and cyclododecanone (musk-like odor) represented the "unpleasant and arousing" group. The odorants were diluted in dipropylene glycole to create stimuli of similar intensities. The final odor concentrations equaled 30% for most odorants, except for Thesaron and IBA, where the concentration equaled 20%. All odorants and dipropylene glycole were provided by Takasago Europe Perfumery Laboratory S.A.R.L., Paris.

Procedure

Introductory session. Subjects were asked not to eat or drink anything else but water two hours prior to the sessions and not to smoke nor wear perfume on the days of the experiments.

During the first meeting, participants were trained to use the velopharyngeal closure technique. This passive breathing technique prevents sniffing in response to odorous stimulation during the measurement (Kobal, 1981). Afterward, the participants were presented with the odorants. The substances were delivered via a computer-controlled portable olfactometer (OM6b; Burghart, Wedel, Germany) to ensure that the design during the training session and the fMRI session was as similar as possible.

The subjects were asked to rate the intensity of the stimuli on a visual analog scale ranging from 0 (extremely weak) to 100 (extremely strong). The mean intensity of the 6 odorants tested during the training session ranged between 23.9 for Vanillin ($SD = 16.4$) to 33.23. for Thesaron ($SD = 13.10$), and the intensities of odorants were not significantly different from each other (all $ps > .05$).

fMRI experiment & analysis. For concomitant olfactory stimulation and MRI acquisition, a previously described