Emotional Stimulation Alters Olfactory Sensitivity and Odor Judgment

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Abstract

Emotions have a strong influence on the perception of visual and auditory stimuli. Only little is known about the relation between emotional stimulation and olfactory functions. The present study investigated the relationship between the presentation of affective pictures, olfactory functions, and sex. Olfactory performance was assessed in 32 subjects (16 male). Olfactory sensitivity was significantly reduced following unpleasant picture presentation for all subjects and following pleasant picture presentation for male subjects only. Pleasantness and intensity ratings of a neutral suprathreshold odor were related to the valence of the pictures: After unpleasant picture presentation, the odor was rated as less pleasant and more intense, whereas viewing positive pictures induced a significant increase in reported odor pleasantness. We conclude that inducing a negative emotional state reduces olfactory sensitivity. A relation to functional deviations within the primary olfactory cortices is discussed.

Key words: arousal, emotion, olfaction, threshold

Introduction

Odor perception, in contributing to quality of life and to emotional experiences, constitutes an important ability in one's everyday life. It is widely accepted that odors can induce positive or negative affect as well as modulate behavior, autonomic parameters, and cerebral activity (Lorig et al. 1991; Alaoui-Ismaili et al. 1997; Collet et al. 1997; Hummel et al. 1997; Robin et al. 1999; Vernet-Maury et al. 1999; Gottfried et al. 2002). However, little is known about the reverse effects of emotions on olfaction. Some evidence for an impact of emotional state and emotion-related personality traits on olfactory function in healthy subjects has been provided. In a recent study, Chen and Dalton (2005) investigated the effect of emotion and personality on olfactory perception, using emotionally toned film clips to produce emotional states prior to exposition to a suprathreshold odor. They were able to demonstrate faster reactions of neurotic and anxious individuals to emotionally valenced as compared with neutral odors. Additionally, unpleasant odorants were rated as more intense when presented in an emotional as compared with a neutral state. Only men perceived all odorants more strongly in an emotional than in a neutral state (Chen and Dalton 2005). This study suggests that current emotional state influences olfactory processing. Examining normal subjects, Spinella

(2002) found a positive relationship between empathy (defined as a sense of shared experience or feeling with someone) and smell performance. The author suggested that the 2 processes interact via common neural substrates. Further research examining the effect of emotional state on olfactory processing in greater detail, as provided by a combination of threshold and discrimination tasks, is necessary in order to discern possible interactions between different levels of odor processing associated with different brain structures and emotions.

In this context, it is of great relevance that olfaction is a sense closely related to the limbic system and emotions. Recent research has highlighted the close neuroanatomical connection between emotion and olfaction (Royet et al. 2000; Savic et al. 2000; Gottfried et al. 2002; Anderson et al. 2003; Bensafi et al. 2004). Regarding the measurement of olfactory function, Martzke et al. (1997) have highlighted the importance of differentiating between primary (sensory level) and secondary stimulus processing (higher order level). They suggested that whereas the so-called threshold tests such as those implemented in the Sniffin' Sticks test battery (Hummel et al. 2001) supply information at the primary processing level, identification and discrimination tasks are useful in targeting the secondary processing level. Brain areas

underlying the processing of olfactory stimuli have been described in several studies (Zatorre et al. 1992; Sobel et al. 1998; Savic et al. 2000; Anderson et al. 2003; Wiesmann et al. 2004; Winston et al. 2005). According to Doty et al. (1997), the piriform cortex and the amygdala are structures constituting the primary olfactory cortex, whereas the insula and the orbitofrontal cortex belong to the secondary olfactory cortices.

A possible approach to examining the relationship between emotion and olfaction is the experimental alteration of affective state followed by the investigation of subsequent effects on olfactory performance. Visual affective stimuli are broadly employed in emotion induction paradigms and prove very consistent in their effects on self-report and objective parameters assessing emotional experience (Gottfried et al. 2002; Hamm et al. 2003). In order to facilitate the employment of comparable affective images, a standardized set of pictures—the International Affective Picture System (IAPS) (The Center for the Study of Emotion and Attention 1999)—have been developed and is widely applied. It comprises a large range of scenes that vary in their emotional valence (positive and negative) and their evocation of subjective arousal. Although many studies exist showing that the processing of visual, somatosensory, and auditory stimuli are affected by experimental emotion induction (Hamm et al. 2003; Simon-Thomas et al. 2005), the investigation of olfactory functioning is sparse. Research on depression as a typical mood disorder indicates that especially olfactory sensitivity—as measured by threshold tests—is reduced in depressed patients, whereas odor identification and odor discrimination are not affected (Pause et al. 2001; Lombion-Pouthier et al. 2006). Bearing in mind that studies on depression have shown olfactory sensitivity to be affected by negative emotional state, which might be associated with functional deviations in the primary olfactory cortex (Pause et al. 2001, 2003; Lombion-Pouthier et al. 2006), it could be assumed that the induction of an emotional state using affective pictures similarly reduces olfactory sensitivity as measured by threshold tests.

The present study aims at investigating the effect of emotional stimulation on olfactory functions. Additionally, potential sex differences should be uncovered. Using pleasant, unpleasant, and neutral pictures from the IAPS (The Center for the Study of Emotion and Attention 1999), emotional states are induced, and olfactory perception of a neutral odor is subsequently measured by threshold and discrimination tasks taken from the Sniffin' Sticks test battery. We hypothesize that olfactory sensitivity, as measured by the threshold task, should be reduced after unpleasant emotional stimulation while odor discrimination remains unaffected.

Materials and methods

Subjects

The sample consisted of 32 subjects (16 male) with a mean age of 28.7 years (standard deviation [SD] 5.9 years). All sub-

jects reported heterosexual orientation. Age did not differ significantly between male (mean age 28.3, SD 6.2) and female (mean age 29.1, SD 5.9) subjects ($F(1, 30) = 0.14$, P = not significant [NS]). Experiments were conducted in accordance with the Declaration of Helsinki. Ethical approval was obtained. All subjects gave their written informed consent. By means of a screening odor identification test implemented in the Sniffin' Sticks test battery, all subjects were tested for normal olfactory function using available normative data (Hummel et al. 2001). This screening test has shown good test reliability and can be considered a suitable tool for the identification and exclusion of individuals with disturbed olfactory perception (Hummel et al. 2001).

Stimulus material

"Olfactory testing" was performed by means of the Sniffin' Sticks (Hummel et al. 1997). This test battery, based on pen-like odor-dispensing devices, comprises 3 domains of olfactory function, namely odor threshold (olfactory sensitivity), odor discrimination, and odor identification. Due to repeated testing of olfactory function in this study, only threshold and discrimination subtests were applied. All stimuli were presented to both nostrils simultaneously.

Thresholds for n-butanol (16 concentrations) were assessed using a single up-down staircase with a triple forced choice procedure. Three sticks were presented in random order, 2 containing the solvent and the third the odor at a specified concentration. The triplets were repeatedly presented to the subjects until they had correctly discerned the odor. "Olfactory sensitivity" was assessed across all conditions with scores varying between 1 (lowest sensitivity) and 16 (highest sensitivity) relating to the concentration steps of the sticks used. Additionally, subjects were to judge the pleasantness and intensity (on a 9-point scale) of a stick containing n-butanol in a suprathreshold concentration (concentration 1:6).

In the discrimination task, 16 triplets of sticks were presented in random order, with 2 containing the same odor and the third a different odor. Subjects were asked to determine which of the 3 odor-containing sticks differed in smell. Resulting scores ranged from 0 (no correct discrimination) to 16 (perfect discrimination).

The "emotional stimuli" consisted of pleasant, unpleasant, and neutral pictures selected from the IAPS (The Center for the Study of Emotion and Attention 1999). A subset of 150 pictures (50 of each category) were selected for the present study. According to the normative ratings of the IAPS (Bradley and Lang 1994), the 3 emotional conditions differed significantly regarding pleasantness (mean$_{POS}$ 7.1, mean$_{NEU}$ 5.0, and mean$_{NEG}$ 2.9, respectively; $F(2, 147) = 410.8$; $P <$ 0.001), although pleasant and unpleasant pictures yielded higher arousal scores than neutral ones (mean$_{POS}$ 5.6, mean$_{NEG}$ 5.9, and mean$_{NEU}$ 3.0; $F(2, 147) = 138.4$; $P <$ 0.001; post hoc least significant difference [LSD] tests— pleasant or unpleasant vs. neutral: 2.6 and 2.9, respectively;

$P < 0.001$), but did not differ significantly regarding their normative arousal ratings (post hoc LSD tests—pleasant vs. unpleasant: -0.3, P = NS). Pleasantness and arousal during the picture presentation were assessed at the end of each emotional condition using a nonverbal self-report scale. Subjects were asked to rate how pleasant versus unpleasant and how aroused versus calm they felt while watching the emotional pictures with scores ranging from 1 (very unpleasant or low arousing) to 9 (very pleasant or high arousing).

Experimental procedure

Upon arrival, subjects were provided written information concerning the experiment. Their informed consent was obtained. Olfactory perception was assessed using the Sniffin' Sticks test battery. Measurements were taken in 4 conditions: baseline condition (BAS) and positive (POS), negative (NEG), and neutral (NEU) conditions in which pleasant, unpleasant, or neutral IAPS pictures were respectively presented prior to olfactory testing. All 32 subjects took part in the 4 experimental conditions in randomized order, split into 2 experimental sessions in order to avoid a potential systematical habituation effect in olfaction. Figure 1 summarizes the experimental design. The whole experiment lasted approximately 3 h.

The "baseline condition" began with the threshold test, following which the discrimination task was performed.

The experimental design for the "positive," "negative," and "neutral" conditions was as follows. Again, olfactory perception thresholds were initially assessed. A single experimental trial began with 2 IAPS pictures each presented for 5 s. Then, subjects' eyes were masked and a threshold run consisting of 2 triplets was performed. This design was repeated until the threshold test with its performance-dependent number of runs was completed. Subjects were then immediately asked to rate the odorant concentration at a suprathreshold level (dilution 1:6) in terms of pleasantness and intensity. After a short break, the discrimination test was performed beginning with 2 IAPS pictures each presented for 5 s. Subjects' eyes were then masked, and 2 discrimination runs took place. This design was repeated 8 times.

Statistical analysis

First, a main effect of change in the testing procedure between baseline and showing pictures in the single test intervals was verified by subjecting the data (olfactory sensitivity, olfactory discrimination) to analyses of variance (ANOVAs), with the factors picture presentation (baseline vs. neutral picture presentation) and sex (male/female).

Data were analyzed (pleasantness, arousal during picture presentation, olfactory sensitivity, olfactory discrimination, pleasantness, and arousal ratings of the standard odor) for main effects of emotion induction and sex using ANOVAs, with the factors emotional valence (pleasant/unpleasant/neutral) and sex (male/female). Where appropriate, degrees of freedom were adjusted using the Greenhouse–Geiser method. In the Results, uncorrected F values are reported together with the Greenhouse–Geiser epsilon values and corrected probability levels.

Results

Picture presentation

Mean "perception thresholds" and mean "odor discrimination scores" did not significantly differ as a function of picture presentation (threshold: $F(1, 30) = 1.84$, P = NS; discrimination: $F(1, 30) = 2.36$, P = NS) and sex ($F(1, 30) = 1.01$, P = NS) conditions. No significant interaction between the 2 main factors was found.
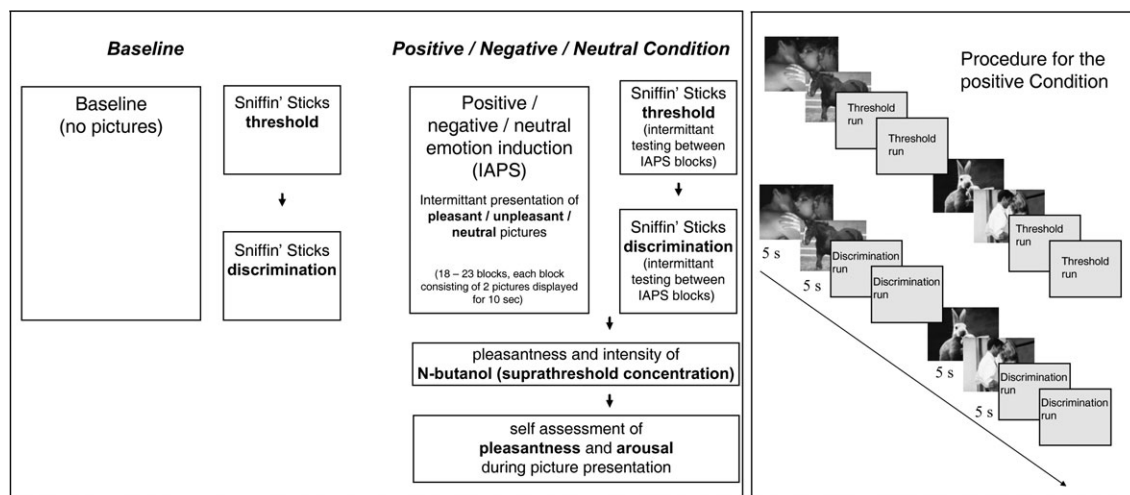

Figure 1   Experimental design (see the text for details).

Emotion induction

Pleasantness and arousal during picture presentation

Figure 2 summarizes the obtained pleasantness and arousal scores. Statistical analyses revealed a main effect of emotional valence on "pleasantness" ($F(2, 60) = 36.59$, $P < 0.001$, $\eta^2 = 0.59$, $\varepsilon = 1.00$) and "arousal" ($F(2, 60) = 24.54$, $P < 0.001$, $\eta^2 = 0.45$, $\varepsilon = 1.00$), but not sex ($F(1, 30) = 0.85$, $P = $ NS; $F(1, 30) = 2.68$, $P = $ NS, respectively) and no emotional valence × sex interaction ($F(2, 60) = 1.01$, $P = $ NS; $F(2, 60) = 1.21$, $P = $ NS, respectively). Post hoc tests confirmed that viewing pleasant pictures significantly increased mean pleasantness and arousal scores, whereas viewing unpleasant pictures significantly decreased pleasantness and increased arousal as compared with neutral picture presentation (all comparisons $P < 0.01$). There was no difference between pleasant and unpleasant pictures with respect to reported arousal.

Olfactory sensitivity

Mean perception thresholds obtained following pleasant, neutral, and unpleasant picture presentation in male and female subjects are depicted in Figure 3.

Statistical analysis revealed a significant main effect of emotional valence ($F(2, 60) = 10.65$, $P < 0.01$, $\eta^2 = 0.26$, $\varepsilon = 0.96$) and a significant emotional valence × sex interaction ($F(2, 60) = 3.47$, $P < 0.05$, $\eta^2 = 0.10$, $\varepsilon = 0.56$). Post hoc analyses showed that olfactory perception thresholds were significantly increased after viewing unpleasant pictures as compared with neutral ($P < 0.01$) and pleasant pictures ($P < 0.05$). The observed difference between positive and neutral conditions did not reach significance. Post hoc analyses also revealed that after viewing pleasant pictures, only male subjects showed a significantly increased olfactory perception threshold as compared with female subjects ($P < 0.05$). No significant differences were observed after viewing neutral or negative pictures.

Olfactory discrimination

Mean discrimination scores (NEG, 11.7; POS, 11.9; and NEU, 11.3) did not significantly differ as a function of emotional ($F(2, 60) = 0.91$, $P = $ NS) and sex ($F(1, 30) = 2.81$, $P = $ NS) conditions. No significant interaction between the 2 main factors was found ($F(2, 60) = 0.71$, $P = $ NS).

Odor pleasantness and intensity

The mean pleasantness scores as a function of emotional valence and sex are depicted in Figure 4. Statistical analyses revealed a main effect of emotional valence ($F(2, 60) = 14.78$, $P < 0.001$, $\eta^2 = 0.33$, $\varepsilon = 0.99$), but not sex ($F(1, 30) = 0.01$, $P = $ NS), and no emotional valence × sex interaction ($F(2, 60) = 1.11$, $P = $ NS) was observed. Post hoc analyses showed in both men and women that after viewing
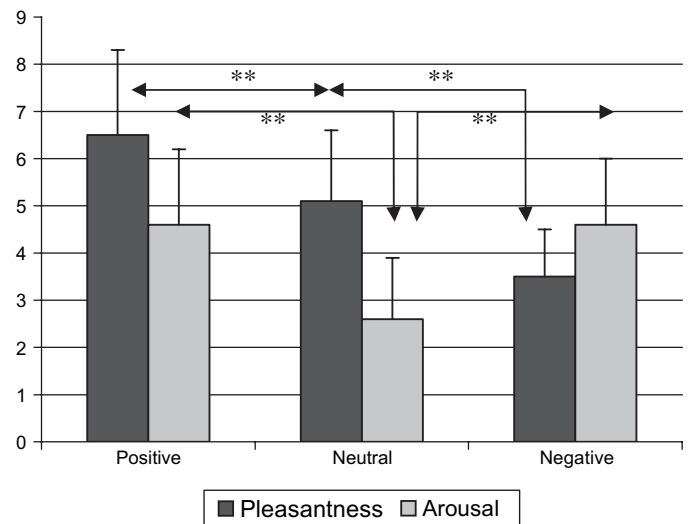

Figure 2 Perceived pleasantness and arousal after positive, neutral, and negative picture presentations. Bars represent SDs (**$P < 0.01$).
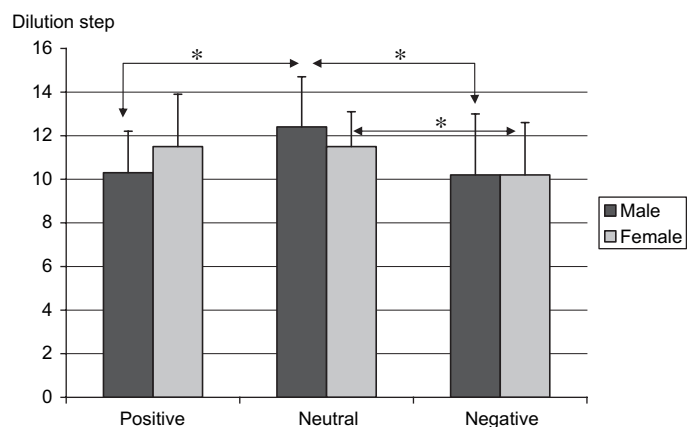

Figure 3 Olfactory detection thresholds after positive, neutral, and negative picture presentations separated for male and female subjects. Bars represent SDs (*$P < 0.05$).

positive pictures the standard suprathreshold odor was rated as more pleasant as compared with that following neutral picture presentation, whereas viewing unpleasant pictures induced a significant decrease in pleasantness (all comparisons, $P < 0.05$).

The mean intensity scores as a function of emotional valence and sex are shown in Figure 5. A significant effect of emotional valence ($F(2, 60) = 9.74$, $P < 0.01$, $\eta^2 = 0.24$, $\varepsilon = 0.97$) and sex ($F(1, 30) = 4.53$, $P < 0.05$, $\eta^2 = 0.24$, $\varepsilon = 0.97$) and a significant valence × sex interaction ($F(82, 60) = 3.22$, $P < 0.05$, $\eta^2 = 0.10$, $\varepsilon = 0.59$) were found. Post hoc analyses indicated that intensity was significantly higher after unpleasant than pleasant or neutral picture presentation ($P < 0.05$). They also showed that male
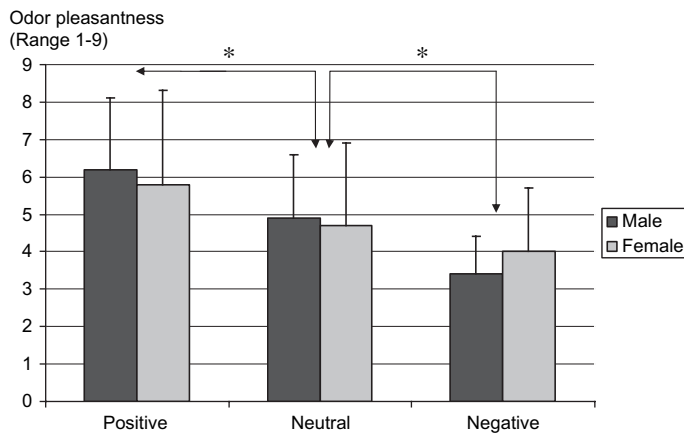
Odor pleasantness
(Range 1-9)

Figure 4 Odor pleasantness judgments after positive, neutral, and negative picture presentations contrasting male and female subjects. Bars represent SDs (*P < 0.05).
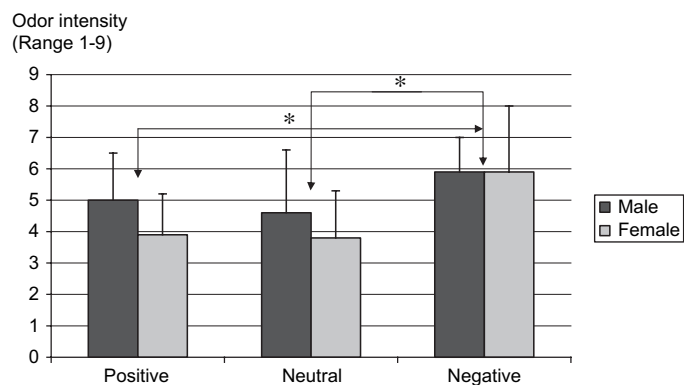
Odor intensity
(Range 1-9)

Figure 5 Odor intensity judgments after positive, neutral, and negative picture presentations contrasting male and female subjects. Bars represent SDs (*P < 0.05; additionally significant higher intensity levels in men were observed, see text for details).

subjects reported significantly higher intensity ratings than female subjects subsequent to neutral and pleasant picture presentations.

Discussion

The present study revealed a clear effect of emotional state on olfaction in healthy subjects. After viewing unpleasant pictures, olfactory sensitivity was significantly reduced. For male subjects, this effect was also present following the viewing of pleasant pictures. Inducing an emotional state did not affect odor discrimination. Judging a neutral suprathreshold odor by means of intensity and pleasantness revealed that—in comparison to neutral picture presentation—pleasantness ratings were decreased subsequent to unpleasant and increased subsequent to pleasant picture presentation. Moreover, unpleasant picture presentation was accompanied by an increase in judged odor intensity. In men, higher intensity ratings were observed across all emotional conditions.

Showing pleasant, unpleasant, and neutral pictures significantly altered the subjects' emotional experience in the expected manner. The induction of emotional states did not differ between male and female subjects as assessed by reported pleasantness and arousal ratings. Importantly, there were no arousal differences between the positive and negative conditions. As no differences were found between baseline and neutral picture presentation, the possibility that observed effects were caused merely by varying the baseline olfactory testing procedure during the emotion induction trials can be eliminated. It can thus be concluded that the good test reliability described for the Sniffin' Sticks battery (Hummel et al. 2001) is also valid when using repeated test sessions as in the present study.

The experienced odor intensity was higher in a negative emotional state than in a neutral state both for male and female subjects. This observation is in accordance with recent data showing that olfactory perception is influenced by the perceiver's cognitive (Dalton 1996; Dalton et al. 1997; Herz 2003; de Araujo et al. 2005) and emotional (Chen and Dalton 2005) state. Concerning cognitive factors, Zald and Pardo (1997) demonstrated that after inducing a negative bias, subjects reported higher levels of odor intensity as compared with a neutral condition. Chen and Dalton (2005) were also able to show that emotional states augmented intensity of odors, whereby—in contrast to our data—this effect was limited to men. In the present study, men also generally reported a higher intensity of odors. Chen and Dalton (2005) argued that a similar effect has also been observed concerning intensity of taste and audition (Dess and Edelheit 1998) as well as of smell (Bensafi et al. 2004). Interestingly, the representation of the intensity of odors has been associated with activity in several brain structures including the piriform cortex (Rolls et al. 2003; Onoda et al. 2005; Zelano et al. 2007) and the amygdala (Royet et al. 2000, 2003; Anderson et al. 2003; Winston et al. 2005), which would also indicate that emotional states may interfere with olfactory processing at a primary level and the corresponding primary olfactory cortices. As other regions such as the insular cortex and the orbitofrontal cortex were reported to be activated when judging the valence of odors or processing unpleasant odors (Zald and Pardo 1997; Royet et al. 2003; de Araujo et al. 2005), results are yet not univocal. Both the insula and the orbitofrontal cortex are consistently activated during the processing of various emotions (see, e.g., Phan et al. 2002) and are also related to the valence of odors (Royet et al. 2000, 2003; Gottfried et al. 2002). Therefore, it cannot be ruled out that secondary olfactory cortices are also modulated by manipulations of emotional state and might be involved in mediating the observed results.

The present study demonstrated that negative emotional experience is accompanied by a reduced olfactory sensitivity, whereas emotion induction has no effect on olfactory discrimination performance. As hypothesized, a negative emotional state affects the primary sensory level of stimulus

processing as measured by threshold tasks. This had already been shown for depressive patients (Serby et al. 1990; Pause et al. 2001, 2003). Song and Leonard (2005) propose that dysfunctions of the limbic system occurring in patients with major depression underlie changes in olfactory perception. They point out that olfactory stimuli strongly activate the amygdala and the orbitofrontal cortex, both of which play an important role in the mediation of emotional experience. As described above, other studies could show that brain structures belonging to the secondary olfactory cortices such as the cingulate and the insula are also involved in the processing of pleasant and unpleasant odors (Zald and Pardo 1997; Royet et al. 2003; de Araujo et al. 2005), and therefore, one must be cautious in arguing that a missing effect of induced emotional state on olfactory discrimination supports the thesis of an alternation in the activation pattern of merely the primary olfactory cortices. Nevertheless, when focusing on brain structures of the primary processing level and the processing of odor valence and intensity, Winston et al. (2005) compared amygdala responses to high- and low-concentration variants of pleasant, neutral, and unpleasant odors and demonstrated that the observed amygdala activation is effectively dependent on valence and is correlated with intensity which is in line to former research data by Royet et al. (2003). Further research employing imaging techniques is necessary in order to uncover whether the observed interaction between a negative emotional state and olfactory sensitivity is also reflected in a corresponding activation pattern of brain structures serving the primary level of olfactory processing.

Concerning possible altered activation patterns of brain structures serving olfactory processing, it is known that judging the hedonic quality or intensity of odors involved many brain structures including the piriform cortex, the amygdala, the insula, and the orbitofrontal cortex (Zald and Pardo 1997; Royet et al. 2000; Gottfried et al. 2002; Zald et al. 2002; Anderson et al. 2003; Onoda et al. 2005; Winston et al. 2005; Zelano et al. 2007). It has been shown that the used emotion induction paradigm modified perceived odor pleasantness and intensity—variables which are strongly interrelated (Bensafi et al. 2002)—and the subsequent altered activity in olfactory processing structures might modify odor sensitivity via top-down processes. In this context, induced arousal could be the relevant mediating variable and could also explain the observed sex differences. Female subjects demonstrated reduced olfactory sensitivity after negative picture presentation, whereas male subjects showed significantly increased olfactory perception thresholds after both negative and positive picture presentation. This result suggests that odor perception in men is strongly interfered with by arousing emotional states, whereas only negative affect lowers odor sensitivity in women. Concerning the observed differences in odor perception between the negative and positive conditions, Herz (2003) suggested that positive stimuli are more sensitive to cognitive and contextual effects than

are negative stimuli, which may be more anchored in sensation and thus governed more by bottom-up perceptual mechanisms. Men could be more susceptible to such cognitive and top-down influences, which may account for the observed reduced olfactory sensitivity after pleasant emotion induction. An interaction between sex and odor perception was also revealed by Chen and Dalton (2005), who found that whereas women detect pleasant and unpleasant odors faster than neutral ones, no differences were found for men. As in the present study, perceived pleasantness and arousal did not differ between male and female subjects, and as there were no arousal differences between the positive and negative conditions, the reduction of olfactory sensitivity after inducing a negative emotional state cannot be explained as a mere result of differences in the level of arousal. Besides, higher intensity ratings for men were observed after positive and neutral picture presentations, suggesting that odor perception in men is possibly more strongly interfered with by emotional states.

In conclusion, the present study provides support for an effect of emotional states on olfactory perception at a primary processing level. A possible methodological caveat of the study refers to the fact that a part of the subjects fulfilled both affective conditions in one session, which might account for similar levels of arousal in the 2 conditions as a carryover effect. This point could be clarified by assessing emotional conditions on separate sessions in forthcoming studies. Future research should also aim to detect possible neural substrates underlying the interaction between olfactory sensitivity and emotional states.

Acknowledgements

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