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Mood Induction with Olfactory Stimuli Reveals Differential Affective Responses in Males and Females

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Abstract

Olfactory perception is characterized by interpersonal variability. Although gender has been identified as a potential influencing factor, currently little is known about its effect on perceived hedonicity of individual odorants. This study assessed gender differences in emotional appraisal of 3 odorants (eugenol, vanillin, and hydrogen sulfide [H_2S]), presented to 25 healthy subjects (13 males, 12 females) in a blocked design. Standardized scales rating valence and judgments of emotional experience were used for stimulus evaluation. Results indicate ambiguous pleasantness ratings for eugenol as well as stronger responses to vanillin odorant in female subjects; furthermore, in emotional experience ratings, the effect of eugenol was found to be gender dependent, evoking more positive and less negative emotions in female subjects than in males. The gender dependence of the mood response to eugenol necessitates reconsideration of this odorant as a reliable gender independent olfactory stimulus for studies on olfaction and emotion.

Key words: emotion, gender, hedonic valence, mood induction, olfaction

Introduction

The human olfactory system is a highly sophisticated sensory modality able to distinguish between thousands of organic compounds (Firestein 2001). While people often struggle to name or label the multitude of smells they encounter in everyday life, emotional appraisal of odors occurs extremely fast and requires little cognitive mediation (Pause et al. 2003). The close link between odor and emotion can be explained by the high degree of overlap between the limbic structures involved in olfactory and emotional processing (Zald and Pardo 1997; Royet et al. 2003; Rolls 2004) and has made olfactory stimulation a promising method for mood induction. During the last decade, paradigms have been developed in which subjects complete cognitive tasks during exposure to odorants of positive or negative valence, which are expected to induce a corresponding positive or negative mood (Crespo-Facorro et al. 2001; Schneider et al. 2006, 2007; Habel et al. 2007). Whereas these studies rely on the stable and universal hedonic properties of the odorants used, recent evidence suggests that some odorants are more liable to interpersonal differences than others, causing emotional appraisal to be highly variable among subjects (Brand and Millot 2001). In particular, conflicting results regarding the hedonic valence of eugenol (clove smell) have been reported. While some authors claim that eugenol is a pleasant olfactory stimulus (Doty 1975; Dijksterhuis et al. 2002), other studies report a negative hedonic valence (Masago et al. 2001). It has further been suggested that due to the high variability of pleasantness ratings, ratings for eugenol average around a mean score that is neither pleasant nor unpleasant (Alaoui-Ismaili et al. 1997).

The aim of the present study was to assess the variability of affective responses to eugenol and 2 other odorants frequently used for mood induction, vanillin and hydrogen sulfide. As a next step, the degree to which interindividual differences can be explained by gender effects was investigated as these have been found to determine a variety of aspects of olfactory processing (Yousem et al. 1999; Brand and Millot 2001; Royet et al. 2003; Koch et al. 2007). To date, the most commonly reported gender differences in olfactory abilities relate to higher olfaction detection and identification abilities of females compared with males. Women were found to report higher perceived intensities and lower detection thresholds (Doty 1989; Wysocki and Gilbert 1989). Also, there is some evidence indicating a female advantage in odor discrimination abilities (Doty et al. 1984; Brand and Millot 2001). To our knowledge, only one study to date has systematically investigated gender differences in odor valence ratings. The National Geographic Smell Survey, conducted in 1989 in collaboration with the National Geographic Society, tested the smelling abilities of 1.5 million people in the United States (Doty 1975; Wysocki and Gilbert 1989) and asked them to rate the quality of a number of odorants on a Likert scale. It was found that men tended to give higher pleasantness ratings than females to amyl acetate and mercaptan but that women rated eugenol and phenethyl alcohol more favorably than men. Although the authors did not address the effects of the observed gender differences on mood induction, one might suspect that the reported differential pleasantness ratings might play a crucial role in emotion studies, both in terms of interpersonal variability of valence ratings (perceived pleasantness) and emotional response (mood induction) ratings.

The present study combined different rating scales of positive and negative affect to assess the subjective experience of each presented odor. In a blocked design, male and female subjects were presented with 3 odorants typically used for mood induction (vanillin, eugenol, and hydrogen sulfide). Subjects were asked to rate perceived pleasantness and intensity of each odor presented. However, as pleasantness ratings do not necessarily reflect successful mood induction, affective rating scales designed to assess emotional states of the subject were also administered. Emotional state after exposure to each odorant was compared with a baseline state acquired after exposure to humidified ambient air introduced as a control condition.

Materials and methods

Subjects

Twenty-five healthy subjects (13 males, 12 females) were recruited from graduate psychology students and research staff of the RWTH Aachen University Hospital and matched for age and years of education. None of the subjects worked on a ward or had daily contact with strong odorants such as disinfectants, and none were involved in research projects dealing with olfactometry. All subjects had grown up in and currently lived in Europe or North America. The mean age was 28.42 (standard deviation [SD] = 8.43) and mean education level 17.08 years (SD = 3.03) for females and 30.92 (SD = 8.15) and 17.00 years (SD = 2.35) for males, respectively. There was no significant difference regarding age between groups ($t = 0.70$, degrees of freedom = 23, $P = 0.46$ [not significant]). Subjects were closely screened for medical, neurological, and psychiatric history and provided written informed consent to participate in the study. Based on self-report, 6 of the female subjects were using oral contraceptives; of the other 6, 2 were menstruating on the day of measurement and 4 were in the luteal phase of their menstrual cycle. One female subject was a smoker, and none of the male subjects were smokers. An olfactory screening with the Sniffin' Sticks test (Hummel et al. 2001), a multiple forced-choice task that allows the differentiation between anosmia, hyposmia, and normosmia, was performed to ensure that all subjects had normal olfactory functioning. The study was approved by the Institutional Review Board of the medical faculty of RWTH Aachen University.

Olfactory stimulant delivery

Odors were delivered in a standardized manner via a Burghart OM4 olfactometer (Wedel, Germany) operating at a constant temperature of 40 °C. This machine delivers odors unirhinally by means of tubing ending in a nosepiece inserted into the right nostril. Short intermittent pulses of odorants alternating with clean ambient air were administered at a constant airflow rate. Subjects were exposed to four 3-min blocks of olfactory stimulation. Each block consisted of 40 pulses of olfactory stimulation, with a pulse length of 1500 ms and an interstimulus interval of 3500 ms. The olfactory system habituates rapidly to sensory input, especially during continuous odorant flow (Poellinger et al. 2001); therefore, the aforementioned presentation mode was chosen to minimize susceptibility to habituation. Presentation times were adapted from previous studies, which have successfully induced moods through odorants in healthy control subjects (Schneider et al. 2006, 2007; Habel et al. 2007; Koch et al. 2007) without evidence of habituation in the magnetic resonance signal in the relevant areas.

Odors were humidified to prevent any thermal irritation or drying out of the nasal mucosa and airflow summed up to 6 l/minute. This was achieved by combining 4 l/minute of odorant during the smell pulses with 2 l/minute of humidified air. During the interval between pulses, flow rate remained the same, with 6 l/minute of humidified air delivered.

Vanillin odorant was prepared by dissolving 1 g vanillin powder in 10 ml propylene glycol, eugenol odorant was prepared by combining 1 ml eugenol solution with 10 ml propylene glycol. Hydrogen sulfide (H_2S) odorant consisted of hydrogen sulfide in nitrogen at a concentration of 20 parts per million. These odorants were chosen in order to minimize trigeminal impact because they are rarely detected by anosmics (Doty et al. 1978). Blocks of olfactory stimulation (hydrogen sulfide [H_2S], eugenol [E], vanillin [V], and a neutral condition of water saturated air [N]) were delivered in 1 of 3 possible permutations ([V, N, H_2S, E], [E, H_2S, N, V], and [H_2S, V, N, E]).

The 3 versions were chosen among all possible permutations so that confounds between relevant odorant characteristics and the position within the experimental protocol would be reduced (e.g., each odor was in one permutation preceded by a neutral block. Also, some subjects received vanillin before and eugenol after H_2S, which was generally rated most intense, and vice versa).

Throughout the study, subjects were instructed to focus their attention on a fixation cross presented on a computer screen. They were not told in which sequence the odorants would be presented or what each olfactory stimulus would be; subjects sat with their back to the olfactometer, unable to observe actions of the examiner.

Emotional self-rating

After each block of olfactory stimulation, the subject was instructed by the examiner to rate the pleasantness of the presented odor on a Likert-type rating scale ranging from –3 (extremely unpleasant) to +3 (extremely pleasant), with 0 indicating a neutral affective value. They were then asked to assess odor intensity on a scale ranging from 1 (imperceptible) to 7 (extremely intense). The subjective mood changes were assessed with the positive and negative affect schedule (PANAS, Watson et al. 1988), a 5-point unipolar intensity scale consisting of two 10-item mood scales intended to assess positive and negative affective experience, respectively. The scale requires ratings of "How did you feel during the last few minutes?". Furthermore, the emotional self-rating (ESR) scale (Schneider et al. 1994) was used to assess the intensity of specific felt emotions (on a 5-point unipolar intensity scale, i.e., whether subjects felt happy, sad, surprised, angry, fearful, or disgusted during the mood induction procedures). We decided to administer both rating scales because of their complementary advantages; due to the more indirect way of addressing emotional responses (asking for intensity of 10 different emotional adjectives associated with positive and negative emotional states), the PANAS is less subject to response tendencies, that is, social desirability; however, the ESR can inform about the subjects' ability to differentiate emotional quality because it distinguishes between the 6 universal emotions as defined by Ekman (1992), Ekman et al. (1987), and Ekman and Friesen (1971). However, due to the very direct answer format, it possesses greater affinity to the social desirability bias. The concept of "universal emotions" was incorporated into the study despite ongoing debate as to the number of "basic" emotions (Izard 1985; Oatley and Johnson-Laird 1987; Ortony and Turner 1990) and as to whether these really constitute discrete biological categories (Phan et al. 2002; Barrett 2006). Despite some cultural differences in emotional expression, evidence suggests that these 6 emotions are considered to be meaningful across cultural boundaries (Elfenbein and Ambady 2002; Waller et al. 2008), and therefore, separate ratings for each of these emotions were thought to provide additional information in the context of the present study with respect to the exact valence of the induced emotion.

Statistical analysis

Analyses of variance (ANOVAs) were performed on all the divergent measures taken to assess differences in hedonic valence of the odorants used. For intensity and valence ratings, a 2×4 repeated measurement ANOVA was performed, with gender (female vs. male) as the between-subject factor and odorant type (hydrogen sulfide, eugenol, vanillin, and ambient air) as the within-subject factor. Subsequently, significant effects were decomposed by Student's *t*-tests in an exploratory fashion to identify significant differences. In order to determine whether pleasantness ratings were a function of intensity, correlations between the 2 ratings were conducted separately for each odor.

A positive and a negative affect score were calculated for each subject from the corresponding PANAS ratings. A 3-way repeated measures analysis of covariance (ANCOVA) was then conducted with gender as the between-subject variable and odorant type as well as positive versus negative PANAS score as the within-subject variables. Stimulus intensity was included as a covariate. To find out to which extent hedonic valence ratings of female participants might be related to hormonal levels, separate 2×4 repeated measurement ANOVAs were calculated with hormonal status (oral contraceptives/no oral contraceptives) as the between-subject variable and odorant type as a within-subject variable separately for the intensity and pleasantness ratings and also for the positive and negative PANAS scores. Whenever a significant relationship emerged here, this factor was included as a covariate in the ANOVA.

Decomposing significant interaction effects, separate 2×2 ANOVAs for each odorant where performed, with PANAS score as a within-subject factor and gender as a between-subject factor. Paired *t*-tests were then conducted in an explorative manner to further decompose interactions. For ESR scores, separate repeated measurement ANOVAs were calculated for each emotion, with gender as the between-subject variable and odorant type as the within-subject variable. Levene tests for the homogeneity of variables revealed unequal variances in a number of cases; however, parametric analyses were applied throughout the analyses as the ANOVA is quite robust against violations of equal variances at group sizes between 10 and 20, as present in our case (Box 1954). Greenhouse–Geisser corrected P values are presented.

Results

Intensity/pleasantness ratings

The intensity ratings of the female group did not vary depending upon hormonal status. There was a significant effect of odorant type on the intensity ratings (F [2.74,63.01] = 29.67, $P < 0.001$) which was unaffected by the subject's gender. Pairwise comparisons revealed that vanillin was judged to be significantly less intense than hydrogen sulfide ($P = 0.01$) and that the ambient air condition was judged to be significantly less intense than any other odorant ($P < 0.001$). Eugenol and vanillin did not differ significantly in intensity.

For pleasantness scores, there was a significant main effect of oral contraceptives when comparing females based upon hormonal status ($F[1,10] = 6.531$, $P = 0.029$), indicating that females on hormonal contraceptives gave lower pleasantness ratings to all presented odors than females without hormonal contraceptives. Hence, this factor was included as a covariate in the ANOVA. Consequently, a main effect of odorant ($F[2.60,57.20] = 35.79$, $P < 0.001$) emerged. Pairwise comparisons showed that vanillin was rated as more pleasant than any other odor ($P < 0.001$) and hydrogen sulfide was rated as less pleasant than any other odor ($P < 0.001$). Eugenol and ambient air did not differ significantly in their pleasantness ratings (Figure 1).

A trend for an interaction of odorant type with gender was also observed ($F[2.60,57.20] = 2.77$, $P = 0.057$) as well as a trend for a main effect of gender ($F[1,22] = 4.22$, $P = 0.052$). Explorative post hoc *t*-tests indicated that, although both groups rated vanillin the most pleasant odor, females rated vanillin more favorably than men ($t = -2.029$, $P = 0.027$). No gender-specific effects were found for any other odorant condition. Also, intensity and pleasantness ratings were correlated for H_2S ($R^2 = -0.575$, $P = 0.003$) but not for any other odor.

PANAS scores

An ANCOVA performed with the intensity ratings for each odorant as covariates did not show any significant influence of stimulus intensity. Therefore, ANOVA results are reported. Mean values per odorant and gender subgroup are shown in Table 1.

A main effect of odorant type was observed ($F[1.71, 39.30] = 7.47$, $P = 0.003$) as well as a main effect of positive versus negative PANAS score ($F[1,23] = 25.01$, $P < 0.001$).

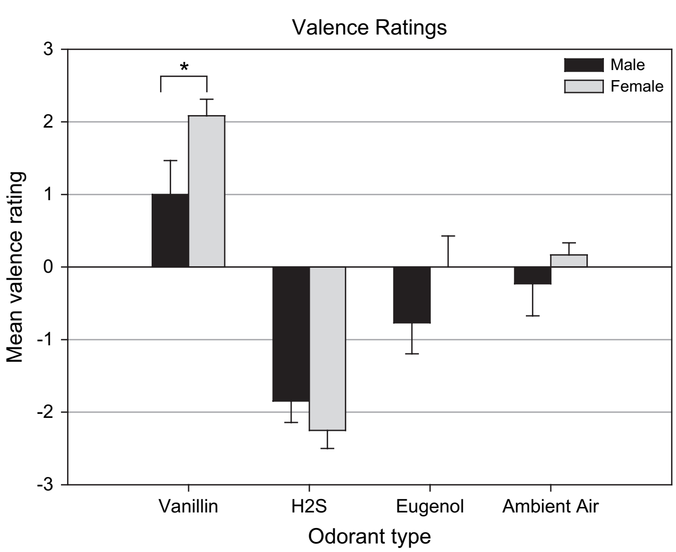

Figure 1 Mean pleasantness ratings separately for each odorant. Error bars depict +/−1 standard error. The asterisk depicts a significant gender interaction ($P < 0.05$).

There was also an interaction between odorant type and PANAS score ($F[2.52,57.99] = 8.85$, $P < 0.001$), indicating that for some odorants, a positive affect prevailed, whereas for others, more negative affect was experienced.

Furthermore, a 3-fold interaction of odorant, PANAS score and gender emerged ($F[2.52,57.99] = 3.272$, $P = 0.035$).

When the effects were decomposed conducting separate 2×2 ANOVAs on each odorant, a gender-specific pattern could be shown for eugenol but not for any other odorant. Figure 2 illustrates the observed effects. A significant difference between positive and negative scores without a gender interaction was found for vanillin ($F[1,23] = 50.61$, $P < 0.001$) and for ambient air ($F[1,23] = 9.61$, $P = 0.005$), with subjects rating positive aspects of their emotional state more highly than negative aspects. No significant effects could be shown for H_2S.

For eugenol, an interaction between PANAS score and gender emerged ($F[1,23] = 6.30$, $P = 0.02$). To further explore this relationship, between-subject *t*-tests were conducted. These confirmed that females achieved higher positive PANAS scores ($t[22,62] = -1.72$, $P = 0.049$) and lower negative PANAS scores ($t[14,66] = 1.87$, $P = 0.041$) than males.

Upon analysis of female participants separately, no influence of hormonal status on PANAS ratings was found for any odorant.

ESR

Mean ratings for each of the 6 subscales per odorant are depicted in Table 1.

For "anger" ratings, a significant main effect of odorant type was found ($F[2.12,46.59] = 7.97$, $P = 0.001$).

Pairwise comparisons of this main effect revealed a significant difference between H_2S and vanillin ($P < 0.001$) and between H_2S and ambient air ($P < 0.001$) with H_2S receiving higher anger ratings. No other significant differences could be found.

When "disgust" ratings were compared across odors, a significant main effect of odorant type was found ($F[2.29, 52.87] = 63.573$), $P < 0.001$). Pairwise comparisons revealed that H_2S was rated higher in evoking disgust than any of the other odorants at $P < 0.001$. Both vanillin and ambient air achieved extremely low disgust ratings; however, even less variability in the disgust ratings for vanillin than ambient air was observed so that the disgust ratings for vanillin were significantly lower than for eugenol ($P < 0.001$). However, neither vanillin nor eugenol differed significantly from ambient air (see Table 1).

For "happiness" ratings, there was also a main effect of odorant type ($F[2.19,50.47] = 11.19$, $P < 0.001$). Vanillin evoked significantly more happiness than H_2S ($P < 0.001$), eugenol ($P = 0.01$), and ambient air ($P < 0.001$). Additionally, H_2S evoked less happiness than eugenol ($P = 0.01$) and ambient air ($P = 0.04$).

For "sadness," we also found a main effect of odorant ($F[2.21,50.79] = 4.144$, $P = 0.018$). Pairwise comparisons

Table 1 Mean ESR and PANAS ratings separately for males and females

		Vanillin	H_2S	Eugenol	Ambient air
Anger	♂	1.31 (0.63)	2.08 (1.00)	1.77 (1.17)	1.15 (0.55)
	♀	1.00 (0.00)	1.75 (1.22)	1.08 (0.29)	1.00 (0.00)
Disgust	♂	1.46 (0.88)	3.62 (1.39)	2.15 (1.28)	1.46 (0.97)
	♀	1.00 (0.00)	3.67 (0.89)	1.58 (0.67)	1.17 (0.58)
Happiness	♂	2.23 (1.24)	1.15 (0.55)	1.38 (0.77)	1.54 (0.78)
	♀	2.75 (1.29)	1.25 (0.45)	2.08 (0.90)	1.67 (0.78)
Sadness	♂	1.00 (0.00)	1.54 (0.78)	1.46 (0.78)	1.23 (0.60)
	♀	1.00 (0.00)	1.08 (0.29)	1.08 (0.29)	1.00 (0.00)
Surprise	♂	1.92 (1.04)	1.92 (1.19)	1.38 (0.51)	1.54 (1.13)
	♀	1.50 (0.52)	1.75 (1.06)	1.50 (1.00)	1.17 (0.39)
Fear	♂	1.15 (0.38)	1.62 (1.19)	1.38 (0.65)	1.23 (0.60)
	♀	1.00 (0.00)	1.33 (0.89)	1.00 (0.00)	1.00 (0.00)
PANAS positive	♂	23.77 (9.53)	19.54 (6.44)	18.00 (6.84)	16.62 (6.06)
	♀	20.92 (6.32)	16.92 (4.50)	22.83 (7.17)	15.75 (6.33)
PANAS negative	♂	12.46 (2.93)	17.15 (7.47)	15.85 (7.34)	12.77 (4.48)
	♀	10.25 (0.62)	17.58 (9.10)	11.83 (2.37)	10.58 (1.24)

Standard deviations are indicated in brackets.

revealed that vanillin differed significantly from H_2S ($P = 0.02$) and from eugenol ($P = 0.03$). No other significant effects were found.

For "surprise" and "fear," no significant effects were found.

Discussion

The present study was designed to test and compare the reliability of the affective response to 3 odors commonly used in mood induction studies. We further aimed to find out to which extent the subject's gender served as a predictor for emotional experience. It was found that perceived pleasantness and emotional affect evoked by eugenol could not as clearly be assigned a positive or negative hedonicity as this was the case for the 2 other odorants, vanillin and H_2S. Importantly, eugenol was also more liable to gender effects in mood induction than vanillin or hydrogen sulfide, providing a possible explanation for the observed effects.

As it was not possible to consistently establish the emotional valence of eugenol in stimulus evaluation ratings or affective responses, this odorant seems unsuitable for use in mood induction. This finding is in line with the results of previous studies such as Alaoui-Ismaili et al. (1997) and contrasts with the results for H_2S and vanillin. For these 2 odors, the positive and negative hedonicity judgments that were found, respectively, match the affective responses reported by previous research (Kobal and Kettenmann 1999) and are reflected in both the PANAS and ESR scales. H_2S is commonly rated as unpleasant and evokes negative emotions, whereas vanillin is generally rated as pleasant and correspondingly evokes positive emotions. Although our intention in including the ESR was to further specify the emotional quality of the odorant, it has to be noted that Vanillin scored high on happiness and equally low on anger, sadness, and disgust, whereas the opposite pattern emerged for H_2S. None of our odorants proved to specifically induce fear or surprise. These results are in line with the claim that vanillin and H_2S, in contrast to eugenol, do reliably produce positive versus negative affect in a healthy control sample; however, they also indicate that valence judgments using the PANAS might be more sensitive to detect emotion shift in positive or negative direction while more direct emotional measures, such as ESR, tapping the "basic" emotions are less sensitive. Also, it seems plausible that the small range of the ESR scale might have contributed to overlap of ratings between odorants.

There is scarcity of studies that explore factors that influence the emotional appraisal of odorants; therefore, the influence of one specific candidate factor, gender, on affective responses to odorants was investigated.

Interestingly, odor valence and subjective experience ratings seemed differentially affected by gender: female subjects' mood seemed positively affected by the clove smell of eugenol odorant, which did not appear to be the case for male subjects. At the same time, explicit valence ratings for eugenol did not differ significantly between males and

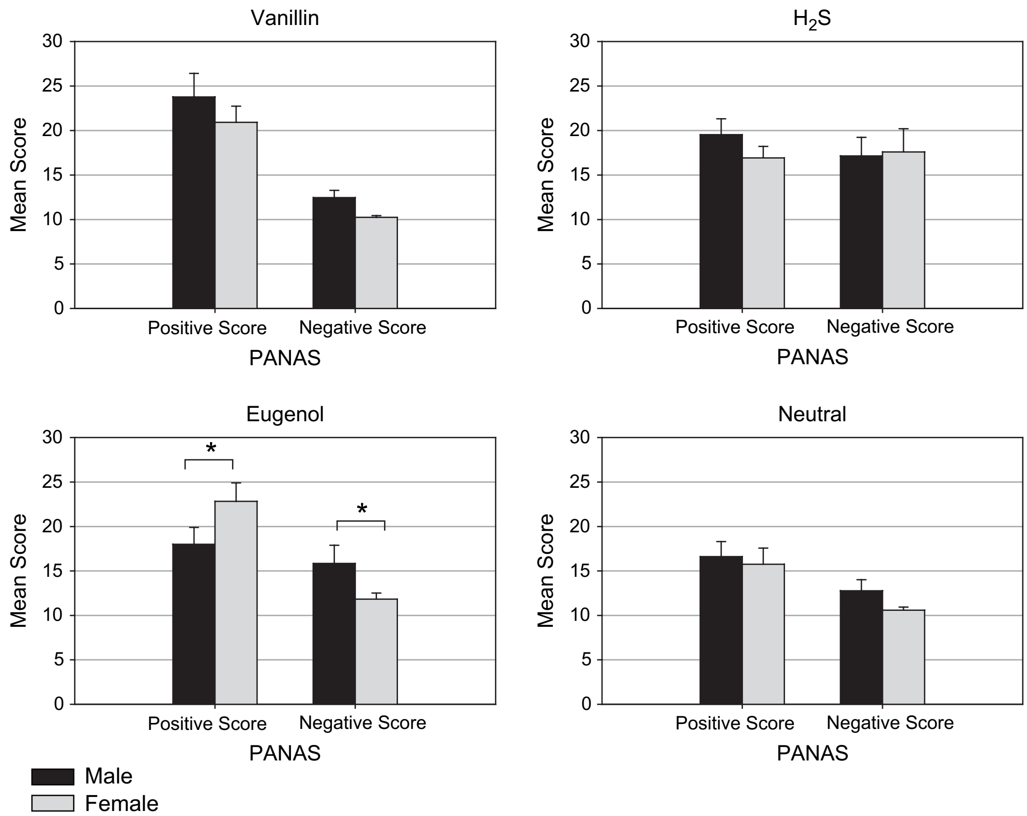

Figure 2 Mean PANAS scores after exposure to olfactory stimulation blocks, separately by odorant. Error bars depict +/−1 standard error. The asterisks depict a significant gender interaction ($P < 0.05$).

females; however, vanillin was rated more positively by females than by males in the valence ratings but had no differential effect on mood induction.

These results provide additional support to an increasing body of research suggesting gender differences in olfactory processing and confirm the need to investigate influencing factors that may explain the reported differences, which currently remain speculative, especially with respect to the observed differences between implicit and explicit measures.

Over the past decade, evidence has accumulated showing that an observed heightened sensitivity of females' olfactory abilities in comparison to males' is reflected in functional differences between male and female olfactory brain structures. Higher activation levels have been found in inferior frontal regions during passive smelling tasks as well as during intensity rating tasks for female subjects (Levy et al. 1999; Yousem et al. 1999). However, Bengtsson et al. (2001) suggest that anatomical differences might not be present at the level of odor perception but that women are more prone to involving cognitive processes in passive smelling tasks, which would be reflected in the observed enhanced caudate nucleus and insula activations. A similar claim is made by Levy et al. (1999), who hypothesized that the observed differences were mainly a result of gender differences in cognitive styles. In the current debate, there are 2 different viewpoints that purport to explain the diverging hedonic judgments of males and females. One emphasizes the impact of associative learning and another offers an explanation from an evolutionary perspective.

The associative learning viewpoint claims that higher pleasantness ratings in females reflect a more accomplished sense of smell which results from more frequent exposure to certain odorants in everyday life. This view implies that preferences for odors might be acquired during the course of one's life and that women may be exposed more frequently to spices and cosmetic fragrances, resulting in better discriminative abilities and an "acquired taste" to these odors (Yousem et al. 1999; Brand and Millot 2001; Stockhorst and Pietrowsky 2004). In fact, evidence from neonates suggests that early emotional appraisal of odorants is rudimentary and rather a result of associative learning than of innate neural mechanisms (Soussignan et al. 1997). It is conceivable that such a mechanism might have affected pleasantness ratings for vanillin in females in comparison to males as this odorant is in fact much more frequently contained in female's cosmetic fragrances than in male's. It could also be claimed that eugenol might be associated with activities traditionally taken up more frequently by women such as cooking (cloves) and cleaning (eugenol is frequently used in disinfectants). However, whether above-average exposure to such activities would hold true for a sample of young female university students and graduates, as investigated in this study, is clearly debatable; also, whether such activities would generally be perceived as rewarding seems to vary largely.

An alternative point of view takes into account that several sensory modalities have been found to be more sensitive in women and stresses possible evolutionary explanations. It is claimed that women's sensory abilities compensate for weaker physical strength and provide them with alternative abilities that would serve a division of labor (Velle 1987). In particular, superior female chemical senses would allow them to make more reliable judgments regarding the toxicity and edibility of different compounds (Brand and Millot 2001), which could be hypothesized to in turn affect their hedonic judgment. The fact that this study found that women who were not taking contraceptives rated stimulus intensity as higher speaks in favor of an evolutionary approach. In fact, it seems likely that exposure and evolutionary components both contribute to the observed effects, possibly acting differentially on hedonic valence and emotional experience ratings. Future studies should include questionnaires aiming to capture associations evoked by odorants to find out more about the effect of long-term associative learning on odorant hedonicity judgments.

A point that requires further discussion concerns the possible evolutionary mechanisms related to the variability of hedonic judgment across the menstrual cycle. Substantial evidence indicates an effect of hormonal state on olfactory abilities. It has been shown that neuronal responsiveness varies across different stages of the menstrual cycle (Pause et al. 1996). Also, there is evidence that women experience lowered olfactory thresholds during ovulation compared with other cycle phases (Navarrete-Palacios et al. 2003), although a recent study suggests that this might only apply to odors of social and reproductive relevance; thresholds for this type of odor were found to be lower in spontaneously cycling women compared with women on hormonal contraceptives. However, women using oral contraceptives were shown to have lower thresholds for environmental odors compared with spontaneously ovulating women (Lundstrom et al. 2006). Although information on a possible influence of hormonal state on hedonicity judgments of odors is sparse, a recent study from our laboratory indicates effects of hormonal status on emotion recognition in emotional faces (Derntl et al. 2008). Future studies should aim at addressing this issue in a larger sample of naturally cycling women.

A final point is that in matching gender subgroups, equal distribution of dental experience was not controlled between groups. This factor has however previously been suggested to play a role in the emotional valence rating of eugenol due to its use in restorative dentistry (Robin et al. 1998, 1999). Further inquiry into this issue revealed that, in Germany, eugenol is these days very infrequently used in dentistry, that is, predominantly as a disinfectant in temporary filling cements that are not used as standard treatment. The much more frequently smelled odor in dental practices nowadays appears to be that of camphorated and mentholated chlorophenol. Although it therefore seems unlikely that eugenol exposure in the context of dental treatment will have differentially influenced the male or female subgroup to an extent as to fully account for the observed effects, especially in view of the young average age of subjects, future studies should include a more detailed questionnaire on dental experience to rule out this factor.

In conclusion, the present study confirms that vanillin and H_2S have stable hedonic properties and therefore are suitable for mood induction studies. In contrast, an attempt to induce a specific mood with eugenol has raised a number of concerns. Results indicate that implicit and explicit hedonicity ratings are differentially affected. Furthermore, these findings support the consideration of gender as an important influencing factor on olfactory and emotion processing and should stimulate further research regarding the origins of these differences.

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