Increased Odor Detection Speed in Highly Anxious Healthy Adults

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Abstract

Anxiety can either impair or enhance performance depending on the context. Increased sensitivity to threat seems to be an important feature of sensory processing in anxiety since anxious individuals tend to be more attentive to threatening visual stimuli. Evidence of anxiety effects in olfaction is rare; though alterations of olfactory performance in psychiatric patients and some effects of trait and state anxiety on olfactory performance have been reported. Our main objective was thus to investigate whether olfactory processing speed varies as a function of trait anxiety levels. We additionally investigated a possible preferential bias for unpleasant odors in highly anxious participants. Thirty-eight healthy adults participated in a simple odor detection task, where response times (RTs) and anxiety levels were measured. We compared RTs to a pleasant and an unpleasant food odor between high- and low-trait anxiety participants. We found that high-trait anxiety participants detected both odors faster than low-trait anxiety participants, independently of odor pleasantness. Moreover, trait anxiety levels significantly correlated with reaction times to both odors, indicating that trait anxiety but not odor pleasantness influences olfactory detection speed. These findings provide new insights into olfactory processing in healthy adults showing how various levels of trait anxiety affect the olfactory modality.

Key words: anxiety, bias, odor pleasantness, olfactory, processing speed

Introduction

Anxiety is an unpleasant and sometimes pervasive emotional state, which may impact several spheres of an individual’s life. From milder manifestations of anxiety, like moderate perfectionism, to serious disorders such as agoraphobia or post-traumatic stress disorder, anxiety often influences performance in tasks involving various sensory modalities and cognitive functions. Whether anxiety impairs or enhances performance depends in part on the difficulty level and the nature of the task (Eysenck and Calvo 1992), as well as the participants themselves (Bresin et al. 2011). At the participants’ level, self-conscious experiences like self-awareness, self-criticism, worries, and rumination are commonly encountered in anxious individuals and may interfere with task demands, leading to poorer performances (Eysenck and Calvo 1992; Eysenck et al. 2007; Bresin et al. 2011). On the other hand, in certain circumstances, higher vigilance, arousal, and desire to perform in highly anxious people may lead to enhanced performances (Calvo and Alamo 1987; Bresin et al. 2011). Participants’ performance appears to be more impaired by high levels of anxiety when the task is highly difficult and/or requires an important short-term memory component (Eysenck and Calvo 1992). On the other hand, relatively easy tasks requiring little cognitive load such as fine motor tasks, do not usually seem to be affected by increasing anxiety levels (Eysenck and Calvo 1992).

One key feature inherent to anxious individuals is an enhanced sensitivity to environmental threats, with anxious persons being more prone to detect and being more distracted by threats in the environment than their non-anxious counterparts (Mathews and McLeod 1994; Frewen et al. 2008). Accordingly, both clinically anxious and high-trait or state anxious individuals display enhanced selective visual attention to threats, which is reflected by faster reaction times to threatening and/or ambiguous than to non-threatening visual stimuli, and by slower reaction times to neutral targets in the presence of threatening visual distracters (Fox et al. 2001; Frewen et al. 2008; Garner 2010). Despite the unquestionable evolutionary utility of the normal awareness
to potential dangers shown by the common person, an excessive sensitivity to threats can be problematic, especially when the presumed threats do not represent real danger.

Although the existence of a cognitive bias for threatening visual material in anxious people now seems to be clearly established, evidence of such bias in olfaction is scarce, as only a few studies have investigated the influence of mental state and/or health on olfactory processing. For instance, patients suffering from major depression were shown to exhibit reduced general olfactory function (Pause et al. 2001). With regard to anxiety disorders, patients suffering from post-traumatic stress disorder tend to perform better in odor identification tests and respond faster to CO$_2$, an unpleasant stinging gas which acts on the trigeminal system (Croy et al. 2009). Furthermore, patients suffering from various anxiety disorders have been shown to be less accurate at discriminating odors and showed higher intensity estimates and increased valence rating ranges to odors from the Sniffin’ sticks test than control participants, whereas their olfactory threshold and ability to identify odors were generally not affected (Clepe et al. 2012).

Overall, these findings strongly suggest that psychiatric disorders can significantly affect olfactory function. Concerning non-clinical populations, a more limited literature suggests that trait and state anxiety can also affect olfactory performance; however, the nature and direction of this effect has not been clearly established. Although they are closely related, trait and state anxiety represent fundamentally different concepts; state anxiety refers to a transitory emotional state characterized by subjective perceived feelings of tension and apprehension that fluctuate over time (Spielberger et al. 1983), whereas trait anxiety refers to individual differences in anxiety proneness that are relatively stable over time (Spielberger et al. 1983). Recent findings suggested state anxiety effects on olfactory processing, with young healthy adults exhibiting a positive correlation between state anxiety levels and unpleasant odor discrimination accuracy (Krusemark and Li 2012). These behavioral observations were paralleled by the finding of higher skin conductance rate changes, higher BOLD signal changes in the piriform cortex, and increased functional connectivity between this cerebral region and emotion-related brain areas (amygdala and hippocampus) in response to negative odors during odor detection in high-trait anxiety individuals (Krusemark and Li 2012).

A first sign that trait anxiety can affect olfaction was provided when high-trait anxious individuals were shown to exhibit lower sensitivity to $n$-butanol, a relatively neutral odorant (Rovee et al. 1973). More recent studies reported contradictory findings regarding trait anxiety effects on olfactory perception. Havlicek et al. (2012) found a positive correlation between trait anxiety (here measured as a subscale of the neuroticism dimension of the Big Five personality model; McCrae and Costa 1997) and olfactory sensitivity, as well as olfactory discrimination accuracy (both measured by using the Sniffin’ sticks test). Kärnekull et al. (2011), on the other side, did not find such a link between neuroticism levels and olfactory thresholds, neither between neuroticism scores and odor ratings. Still, highly neurotic individuals reported increased environmental chemosensory reactivity. In these studies, however, odor valence was not taken into account; hence, there was no evidence for attention or perceptual bias to unpleasant odors. In another study, women high in trait anxiety perceived emotionally valenced (pleasant and unpleasant) odorants to be stronger than neutral odorants. They also displayed faster reaction times to pleasant versus neutral stimuli, whereas high-trait anxious men presented faster reaction times to both pleasant and unpleasant stimuli (Chen and Dalton 2005).

These previous studies suggest olfactory processing may be influenced by trait anxiety levels. However, they do not suggest the existence of a bias for negative olfactory stimuli in high-trait anxiety persons. Nevertheless, this could potentially be due to the nature of the odorants employed in these studies (e.g., a lemon/orange scent for the pleasant and a fecal odor for the unpleasant stimuli; Chen and Dalton 2005), as it has been shown that both pleasantness and edibility can separately affect reaction times and response accuracy to olfactory stimuli, with unpleasant food odors being detected faster than other combinations of edibility and valence (Boesveldt et al. 2010). Boesveldt et al. (2010) interpreted their results from the viewpoint that food odors in particular might warn of potential dangers in the real life, such as the ingestion of rotten food.

In this study, we aimed to explore the association between trait anxiety and olfactory processing. We investigated whether olfactory perception varies as a function of odor pleasantness and as a function of different levels of trait anxiety. Specifically, we compared response times (RTs) and subjective evaluations during the detection of 2 food odors (pleasant and unpleasant) between high- and low-trait anxiety individuals. We used RTs instead of detection accuracy to assess performance to avoid ceiling effects due to the relative easiness of the task employed. We hypothesized that the presence of anxiety affects the olfactory system as it has been shown for the visual system (Mathews and McLeod 1994; Frewen et al. 2008). Specifically, we expected lower reaction times in high anxiety people, reflecting increased olfactory processing in these persons, and we expected this effect to be more pronounced for the unpleasant odor, reflecting the increased sensitivity to threat-related stimuli in high anxiety individuals. This would indicate that anxiety has a generalized effect on sensory perception rather than a specific effect on the visual system. Moreover, we hypothesized that participants would generally respond faster to unpleasant odors, in accordance to previous findings (Boesveldt et al. 2010). We controlled for state anxiety effects, as potential impacts of this factor on olfactory processing have been recently suggested (Krusemark and Li 2012). Because depression may decrease olfactory perception (Pause.
et al. 2001) and because of the high comorbidity between anxious and depressive symptoms, we also controlled for potential depression effects on olfactory performance in our participants.

Materials and methods

Participants

In total, 38 participants (18 women) aged between 18 and 35 years (mean age 24.3 years, standard deviation [SD] = 4.5) participated in this study. Because mean RTs in 2 participants were more than 2 SDs above the global mean, their data were discarded. No participant suffered of any medical condition at the time of the testing and did not report any olfactory problem. Participants were asked not to eat, drink, and/or smoke 1 h prior to the testing session. All participants provided written informed consent prior to testing. The protocol was approved by the ethics board of the University of Montreal.

Stimuli

Two olfactory stimuli were employed: a pleasant food odor (strawberry odor; Frey & Lau) and an unpleasant food odor (fish odor; Givaudan), diluted in propylene glycol (Galenova) to concentrations of 10% and 25%, respectively. These concentrations remained the same across trials and were selected based on a pretest in which participants rated them as falling well above perception threshold and as being equally intense. To ensure participants would respond only to the perceived odors and not to the tactile stimulation produced by the air puffs, odor-free air puffs were also presented as a control condition. Stimuli were delivered birhinally in a pseudorandomized order.

Setting

We used a customized olfactometer (Institute for Biomagnetism and Biosignalanalysis, University of Münster, Germany), which allows for the presentation of air pulses of well-defined duration to deliver the olfactory stimuli (La Buissonnière-Ariza et al. 2012). We connected the outlet channels to odor chambers (50-mL glass bottles, filled with 4 mL of odorant) via polyurethane tubing with 8 mm outer diameter and an inner diameter of 4.8 mm (Fre-Thané 85A; Freelin-Wade). The same polyurethane tubing of approximately 50 cm length was connected to the odor chambers at one end and inserted into the participants’ nostrils at the other end. All tubings were separated to avoid cross-contamination of odors. During odor presentation, air with a flow of 3 L/min was switched into the respective channel. All nasal stimuli lasted 500 ms. We controlled stimulus delivery and response recording using the “Presentation” software (Neurolab) on a PC (AMD Phenom X3 processor) with Windows XP.

Procedure

Participants were tested in 1 session that lasted approximately 45 min. Before the experimental task, they completed the Spielberg State-Trait Anxiety Inventory (Spielberger et al. 1983) and the Beck Depression Inventory (BDI; Beck et al. 1961). Furthermore, we confirmed normal olfactory ability to identify odors by means of a custom-made 4-choice odor identification test with 8 items (pear, cola, rose, peach, eucalyptus, strawberry, cloves, and lemon) contained in bottles of 50 mL. Odors were presented to the participants one at a time, and participants were allowed to smell each bottle as long as they needed to identify the odor. All participants identified correctly at least 7 out of 8 odors.

Participants were tested in 3 blocks of 7.5 min each; they were allowed to rest between the blocks. During the whole procedure, participants were asked to fixate a white cross, presented in the middle of a computer screen. Prior to every nasal stimulation, the white cross was replaced by a red cross, as a signal for the participants to breathe-in. Participants were instructed to detect the presence of the odorants as fast as possible by pressing 1 button and were told not to press the button if an odor-free air puff was presented. On average, participants received a nasal stimulus every 30 s (25–35 s). Each nasal stimulus (pleasant odor, unpleasant odor, and odor-free puff) was presented 5 times per block.

Variables of interest

Anxiety and depression levels

Trait and state anxiety were measured with the Spielberg State-Trait Anxiety Inventory, a widely used standardized questionnaire for measuring anxiety with good psychometric properties (Spielberger et al. 1983). We further measured depression levels in participants using the BDI, which also possesses good psychometric properties (Beck et al. 1961).

Odor detection

We recorded response accuracy and RTs as dependent variables, with higher accuracy and shorter RT indicative of a better performance.

Odor intensity and pleasantness

After each stimulation block, we assessed odor intensity and pleasantness via a visual analog scale ranging from 0 (not intense/very unpleasant) to 10 (very intense/very pleasant). Participants were asked to draw a bar across the scale for both ratings for the 2 odors separately after each block according to their subjective experience of the odors during the entire block. We measured the distance in millimeter.
Statistical analysis

Participants were divided into 2 groups according to their trait anxiety levels using the median (30 points) of the overall sample. We removed participants scoring at the median (n = 3). Hence, 17 of them were in the low-trait anxiety group, whereas the remaining 18 were in the high-trait anxiety group. High- and low-trait anxiety groups did not differ in terms of age (T [1,33] = 1.61, P = 0.116) or sex (χ² [1, 35] = 0.274, P = 0.738; see Table 1).

Only trials with button-press responses were considered for further analysis (in total, 1129 trials). Participants’ performance was evaluated in terms of hit rates (proportion of correct responses) and RTs (only for correct responses in the range 100–2000 ms poststimuli). We also compared false-positive rates (detection of an odor during the presentation of an odor-free puff) between groups. To ensure that the RT distribution was normal, and in accordance with the literature (Olofsson et al. 2012), we performed a log transformation on the RTs. However, for the sake of clarity, we report the non-transformed values (in millisecond) for the descriptive statistics.

To assess potential differences in terms of depression levels between anxiety groups, we first performed 1-way analysis of variances on BDI scores, as well as state anxiety scores as the dependent variables and trait anxiety group as between subject factor. We then performed repeated measures analysis of covariances (ANCOVAs) on log-transformed RT as the dependent variable with odorant (pleasant = strawberry and unpleasant = fish) as within subject factor and trait anxiety group (high anxiety and low anxiety) as between subject factor, and depression levels (BDI scores) and state anxiety scores as covariates. To further investigate potential perceptual differences, we also performed repeated measures ANCOVAs with odorant as within subject factor, anxiety group as between subject factor, intensity and pleasantness as dependent variables, and depression and state anxiety levels as covariates. We calculated partial η² to estimate effect sizes and considered them to be small, medium, and large if η² = 0.01, η² = 0.06, and η² = 0.14, respectively, in accordance with Cohen (1988).

Finally, we performed exploratory analyses on the whole sample to investigate potential sex differences in terms of RT and ratings of intensity and pleasantness. We computed repeated measures analysis of variances with odorant as within subject factor, sex as between subject factor, and RT, odor intensity, and odor pleasantness ratings as dependent variables.

Following the finding of a significant effect of trait anxiety on RT, we decided to further investigate whether trait anxiety levels were correlated to RTs for both odorants in all participants from the complete sample (n = 38). Therefore, we computed Pearson’s partial correlation coefficient between trait anxiety levels and RT to both odors, with depression and state anxiety levels as covariates.

Results

Performance was first assessed via hit rates in the detection of both odors. On average, participants detected the presence of both odors with very high accuracy, succeeding in more than 90% of the trials. Trait anxiety groups did not differ significantly in terms of hit rates for strawberry odor detection (94.4% [SD = 9.2] for high anxiety and 95.4% [SD = 11.2] for low anxiety, respectively; F [1,33] = 0.066, P = 0.8) or for fish odor detection (98.8% [SD = 4.7] for high anxiety and 90.6% [SD = 16.0] for low anxiety, respectively; F [1,33] = 2.35, P = 0.1). No differences emerged either in terms of false-positive rates (11.5% [SD = 11.2] for high anxiety and 12.9% [SD = 16.8] for low anxiety, respectively; F [1,33] = 0.06, P = 0.9). Therefore, to avoid ceiling effects due to the high accuracy of our participants, we decided to perform all subsequent analyses on the RT only.

On average, participants responded to the strawberry odor after 1003 (SD = 299) ms and to the fish odor after 1007 (SD = 264) ms. The strawberry odor (mean = 5.6 [SD = 1.8]) seemed to be rated as more intense than the fish odor (mean = 7.1 [SD = 2.1]), but this difference was not statistically significant when controlling for state anxiety and depression levels (F [1,31] = 1.51, P = 0.228). We did not find anxiety group effects on odor intensity ratings (F [1,31] = 1.20, P = 0.281). We observed a significant effect of odorant on pleasantness, with the fish odor being rated significantly more unpleasant than the strawberry odor (fish: mean = 2.0 [SD = 1.9]; strawberry: mean = 7.8 [SD = 1.4]; F [1,31] = 9.09, P = 0.005). No effect of anxiety was observed for pleasantness ratings (F [1,31] = 0.40, P = 0.53).

We observed a significant and large effect of trait anxiety (F [1,31] = 7.86, P = 0.009, η² = 0.20) on RT (values in log ms), where high-trait anxiety participants reacted after 2.92log(ms) (SD = 0.09; corresponding to mean = 852 [SD = 183]ms) to the strawberry odor and 2.94log(ms) (SD = 0.10; mean = 894 [SD = 211])ms to the fish odor, whereas low-trait anxiety participants reacted more slowly after 3.05log(ms) (SD = 0.11; mean = 1165 [SD = 299]ms) and 3.04log(ms) (SD = 0.10; mean = 1126 [SD = 267]ms) for strawberry and fish odors, respectively. No effects of odorant

Table 1  Demographic characteristics of trait anxiety groups

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<tr>
<th>Anxiety group</th>
<th>Mean age (SD)</th>
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<td>Low trait anxiety</td>
<td>25.5 (5.6)</td>
<td>7 41.2</td>
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<tr>
<td>High trait anxiety</td>
<td>23.0 (3.43)</td>
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were found \((F[1,31] = 0.01, P = 0.907; \text{see Figure 1})\). We observed significant state anxiety differences between high-(mean = 34.8 [SD = 7.3]) and low- (mean = 25.4 [SD = 4.6]) trait anxiety participants \((F[1,33] = 20.33, P < 0.0001)\). We also observed significant group differences in terms of BDI scores between high- (mean = 8.2 [SD = 7.7]) and low- (mean = 3.5 [SD = 3.0]) trait anxiety \((F[1,33] = 5.35, P = 0.027)\). Nevertheless, as the ANCOVA showed, neither state anxiety \((F[1,31] = 0.066, P = 0.799)\) nor depression levels \((F[1,31] = 0.312, P = 0.580)\) played a significant contribution to trait anxiety effects on RT. There was no significant group \(\times\) odorant interaction.

On average, women responded after 936 ms (SD = 322) to the strawberry odor and after 954 ms (SD = 248) to the fish odor. Men responded after 1032 ms (SD = 264) to the strawberry odor and 1039 ms (SD = 282) to the fish odor. We did not observe significant sex effects on RT \((F[1,36] = 1.11, P = 0.229)\). Women made average odor intensity ratings of 5.6 (SD = 1.7) for the strawberry odor and of 6.9 (SD = 2.3) for the fish odor, whereas men rated the strawberry odor with a mean intensity of 5.6 (SD = 1.7) and the fish odor with a mean intensity of 7.1 (SD = 1.9). No sex differences were found for odor intensity ratings \((F[1,36] = 0.08, P = 0.785)\). Finally, women made average pleasantness ratings of 7.6 (SD = 1.6) for the strawberry and 1.5 (SD = 1.7) for the fish odor. Men rated the strawberry odor with an average pleasantness of 7.6 (SD = 1.5) and of 2.3 (SD = 1.9) for the fish odor. Again, we did not find significant sex effects on odor pleasantness ratings \((F[1,36] = 0.75, P = 0.393)\).

We finally identified a significant and moderate negative correlations between trait anxiety scores and the log-transformed RTs to strawberry \((r[38] = -0.40, P = 0.012)\) and fish \((r[38] = -0.40, P = 0.013)\) odors (Figure 2).

**Discussion**

The aim of this study was to investigate anxiety effects on olfactory processing and a potential bias for unpleasant odors in highly anxious individuals. To address this, we compared RT between participants with high- and low-trait anxiety levels performing an odor detection task using a pleasant and an unpleasant food odor while controlling for potential state anxiety and depression-related confounds and discarding sex effects on RT, intensity, and pleasantness ratings.

As hypothesized, high-trait anxiety participants reacted faster to both odorants compared with low anxiety individuals. According to Cohen’s criteria \((Cohen 1988)\), the effect size of this difference can be considered to be large. In several tasks involving other sensory modalities, impaired and slowed performances were often reported in anxious people. This has been explained, in parts, by the detrimental effects that worries may have on the attention capacities in affected people \((Calvo and Alamo 1987; Eysenck and Calvo 1992; Bresin et al. 2011)\). However, these impairing effects tend to be greater during complex cognitive tasks with high attention and working memory loads, and comparatively appear to have less impact on simple tasks \((Eysenck and Calvo 1992)\) like odor detection. On the other hand, worries about task performance in highly anxious people may lead to an increase in motivation regarding the task, and therefore to the allocation of additional processing resources \((Eysenck and Calvo 1992)\). Moreover, anxious people appear to be more sensitive to failure feedback and are more prone to detect mismatches between performance and expectation, leading them to increase efforts in an effort to increase task performance \((Eysenck and Calvo 1992)\). This may in part explain the faster detection speed encountered in our highly anxious participants. It may also be possible that trait anxiety levels had a greater influence not only on olfactory processing but also on motor speed and/or a proneness to respond because the task we used required pressing a button as fast as possible in order to indicate the presence of an odor. However, high- and low-trait anxiety participants did not differ in terms of false-positive rates, which reduces the possibility of a higher
proneness to respond in our high anxiety subjects. Macaulay (2010) investigated mouse-click speed while participants performed a stressing 4-choice computer task as a function of state anxiety levels and found no evidence of a correlation between anxiety levels and motor speed, such that high anxiety participants did not tend to respond faster than low anxiety participants (Macaulay 2010). Still, to verify the specificity of trait anxiety effects on olfactory processing, future studies should use visual or auditory control tasks to discard potential effects of anxiety on response speed in general. Lastly, higher arousal levels, that is, higher state anxiety levels, could also contribute to faster responses in high-trait anxiety individuals (Calvo and Alamo 1987; Bresin et al. 2011). Indeed, our high-trait anxiety participants displayed also higher state anxiety levels when compared with their low-trait anxiety counterparts. This is not surprising because trait anxiety is a relatively stable measure of anxiety that may be considered as an indication of participants’ susceptibility to experience state anxiety (Spielberger et al. 1983). However, state anxiety levels did not affect trait anxiety effects on RT and did not have a significant effect on RT to any of the 2 odors, suggesting anxiety effects on odor detection speed are specific to trait anxiety.

As our fish and strawberry odors produced similar RTs, our results do not seem to support the previous finding that unpleasant food odors are more quickly detected (Boesveldt et al. 2010). Furthermore, we did not find any evidence for a preferential bias for aversive stimuli in high anxiety individuals (Mathews and McLeod 1994; Frewen et al. 2008). Several factors could potentially explain the absence of pleasantness effects in our study. First, it may be possible that some participants did not consider the fish odor to be unpleasant and the strawberry odor to be pleasant, or that differences between the 2 odors in terms of perceived pleasantness were too small to differentiate the odors. However, participants on average classified the fish odor as unpleasant and the strawberry odor as pleasant, with pleasantness ratings of similar means and SDs as the ones reported by Boesveldt et al. (2010); not to mention that the 2 odors significantly differed in terms of pleasantness. Differences in terms of odor intensity could also have influenced RT because more intense odors could be perceived faster, masking potential pleasantness effects if the pleasant odor was more intense. However, no differences in terms of perceived intensity were found between the odors. At the same, it is possible that the 2 odors did not differ in terms of perceived dangerousness or ecological relevance, although they differed in terms of pleasantness. This should be investigated in future studies using different odors warning of potential dangers such as smoke or gas. Still, Boesveldt et al. (2010) employed the same fish odor and found odor pleasantness effects on detection speed. A potential explanation for the discrepancy between our results (obtained from a French Canadian sample) and Boesveldt’s (obtained from an American sample) might be that cultural differences between the samples could lead to distinct subjective experiences because perceptual judgments such as odor intensity, pleasantness, saliency, and edibility may differ between cultures (Chrea et al. 2004). Further studies may elucidate whether any of these factors could have had any significant impact on our findings.

The more anxious the participants were, the faster they were at detecting odors, regardless of whether they were pleasant odors or not, suggesting some defensive and/or motivational mechanisms are possibly enhanced in anxiety. Although other researchers have also found participants to be faster in detecting both pleasant and unpleasant versus neutral olfactory stimuli, with no difference between pleasant and unpleasant stimuli (Chen and Dalton 2005), more recent work has reported altered odor discrimination in high-trait anxious participants (Krusmark and Li 2012) and in clinically anxious participants (Clepe et al. 2012) for unpleasant odors only, thus supporting the hypothesis of a negative bias in anxious participants in the olfactory modality. Olfactory discrimination, however, is a complex task that requires different cognitive processes such as working memory and decision making. Odor detection, in turn, is a much simpler task, where participants only have to detect the presence of an odor, independently of the odor properties (Hedner et al. 2010). Hence, it is possible that odor emotional valence plays a role in odor processing in anxious people, but that the negative bias found in visual tasks is not necessarily present in olfaction, at least for simple tasks like odor detection. Furthermore, anxiety effects seem to be restricted to odor processing and do not apply to odor perception, as subjective ratings did not differ between anxiety groups.

These findings suggest that anxiety levels in healthy participants do modulate olfactory detection speed, and that this influence is independent of odor pleasantness or participants’ subjective experience. This may reflect a general effect of anxiety features such as increased awareness and motivation, as previously demonstrated for other sensory modalities (Eysenck and Calvo 1992). However, specific effects of anxiety on the olfactory system may also exist. The olfactory system comprises several distinct brain regions such as the orbitofrontal cortex, amygdala, and hippocampus (Zald and Pardo 2000), which are also implicated in emotional processing and regulation (Gottfried and Dolan 2004; Milad et al. 2006; Sehlmeyer et al. 2009), underlying the close relationship between the olfactory and the limbic systems. The amygdala and the hippocampus have been shown to be structurally and/or functionally altered in anxious individuals (Bremner 2004; Milad et al. 2006); these neural alterations in anxiety could in turn have implications on odor processing. Recent findings suggested that primary olfactory cortex activity could also be modulated by anxiety, with anxious adults showing increased preferential responses in the piriform cortex during the detection of emotionally valenced odors (negative in this case; Krusmark and Li 2012). Thus, it is possible that highly anxious participants exhibit altered functioning of
particular brain regions, which in turn lead to decreased RT during odor detection. Future neuroimaging studies comparing high- and low-trait anxiety participants during olfactory and non-olfactory tasks may clarify the exact location, if any, of the effect of trait anxiety on the olfactory system.

Other factors may also have contributed to our findings. First, we did not control for menstrual cycle and oral contraception usage in our female participants. Although there were no sex differences between anxiety groups, and even though potential sex effects on RTs, intensity, or pleasantness ratings were discarded, differences in menstrual cycle phases and/or oral contraception usage between our female participants may have led to differences in their ability to detect the odors, as these factors were shown to modulate olfactory processing in several contexts such as olfactory sensitivity assessment, odor intensity ratings, and odor identification tasks (Derntl et al. 2013). Other between-group hormonal differences could also have influenced our findings. For example, serum leptin levels, which were not measured in this study, have been associated with modulations in odor identification performance, and this effect varied depending on the sex of the participant (Karlsson et al. 2002). Despite the potential influence hormonal levels may have had on our participants’ performance, we believe this should not affect between-group comparisons, as it seems unlikely that there was a systematic inclusion of participants in 1 specific menstrual cycle phase, with higher oral contraception usage, and/or with higher leptin levels in 1 of the experimental groups. Differences in smoking habits could have influenced odor perception and intensity ratings in our participants, as a reduction in olfactory sensitivity in smokers has been previously reported (Ishimaru and Fujii 2007; Katotomichelakis et al. 2007; Hayes and Jinks 2012).

Still, all of our participants reported normal olfactory function and successfully passed a preliminary odor identification task prior to testing, indicating preserved olfactory abilities. Finally, other individual differences such as hunger/satiety levels and circadian phases may have also modulated olfactory processing in our participants, as these factors were not systematically controlled and have been shown to have some effects on olfaction (O’Doherty et al. 2000; Goel and Grasso 2004).

Despite these limitations, we demonstrate in this study that trait anxiety levels in healthy adults are negatively correlated with odor detection RTs. In other words, we found highly anxious participants to be faster at detecting odors than low anxiety individuals, regardless of odor valence, subjective experiences, and/or depression and state anxiety levels. Therefore, even though we did not find evidence for a preferential bias for negative olfactory stimuli in anxious people as demonstrated in the visual modality and suggested by a few recent studies with more complex paradigms in the olfactory modality (Clepe et al. 2012; Krusemark and Li 2012), we show that anxiety does influence processing speed in simple olfactory tasks such as odor detection. We believe that specific neural mechanisms, possibly implicating the piriform cortex and/or medial temporal lobe structures, could underlie the enhanced odor detection speeds observed in anxious participants.

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**References**


