

Not all emotions are equal: Fear chemosignals lower awareness thresholds only for fearful faces

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Abstract

Exposure to body odors (chemosignals) collected under different emotional states (i.e., emotional chemosignals) can modulate our visual system, biasing visual perception. Recent research has suggested that exposure to fear body odors, results in a generalized faster access to visual awareness of different emotional facial expressions (i.e., fear, happy, and neutral). In the present study, we aimed at replicating and extending these findings by exploring if these effects are limited to fear odor, by introducing a second negative body odor – i.e., disgust. We compared the time that three different emotional facial expressions (i.e., fear, disgust, and neutral) took to reach visual awareness, during a breaking continuous flash suppression paradigm, across three body odor conditions (i.e., fear, disgust and neutral). We found that fear body odors do not trigger an overall faster access to visual awareness, but instead sped-up access to awareness specifically for facial expressions of fear. Disgust odor, on the other hand, had no effects on awareness thresholds of facial expressions. These findings contrast with prior results, suggesting that the potential of fear body odors to induce visual processing adjustments is specific to fear cues. Furthermore, our results support a unique ability of fear body odors in inducing such visual processing changes, compared to other negative emotional chemosignals (i.e., disgust). These conclusions raise interesting questions as to how fear odor might interact with the visual processing stream, whilst simultaneously giving rise to future avenues of research.

Keywords: Fear; Disgust; Chemosignals; Visual Awareness; Continuous Flash Suppression

Introduction

Recent developments in research on olfactory communication have increased our awareness of the significant role that human odors play in shaping our emotional, cognitive, and behavioral processes. Human body odors, through conscious (e.g., intensity) and unconscious cues (not associated with perceived properties of the odor), carry multiple bits of information, including characteristics such as genetic relatedness (Jacob et al., 2002), gender (Penn et al., 2007), age (Mitro et al., 2012), as well as variable conditions, such as health (Olsson et al., 2014) and emotional states (de Groot et al., 2012; Mujica-Parodi et al., 2009; Mutic et al., 2016; Prehn et al., 2006; Zhou & Chen, 2009). Human chemosignals also modulate face perception (de Groot et al., 2018; Kamiloğlu et al., 2018; Zhou & Chen, 2009). In the research reported here we extend the latter work, examining how human chemosignals affect the processing of emotional expressions under visually competing conditions (i.e., restricted awareness). The question we pursued was: How do human chemosignals produced under emotion-inducing conditions (i.e., fear, disgust, and neutral) modulate receivers' readiness to perceive facial expressions of emotions (i.e., fear, disgust, and neutral)? In the following, we first provide a short overview of the research on human chemosignals and face perception. We then turn to an overview of the experiment reported here.

Background

Exposure to chemosignals produced in emotional contexts such as fear body odors reveals increased activation of a neural network encompassing emotion-related areas (e.g., amygdala and insula, as well as in the fusiform gyrus and cingulate cortex; Mujica-Parodi et al., 2008; Prehn-Kristensen et al., 2009). This triggers a fear-related state¹ (Mujica-Parodi et al., 2009; Radulescu & Mujica-Parodi, 2013), resulting in psychophysiological and behavioral changes typical of a *sensory acquisition* state (Susskind et al., 2008). These include the activation of the *medial frontalis* muscle – which widens the eye aperture increasing the visual field (Susskind et al., 2008) –, a higher nasal inspiratory volume, as well as faster ocular movement (de Groot et al., 2012).

¹ Please note that by fear-related state we refer to psychophysiological and behavioral functional adaptations triggered by olfactory stimuli, which in this case is fear-related. Throughout the manuscript, we view all the states evoked by chemosignals as pre-conscious functional emotional states (see Adolphs & Andler, 2018) and not as a conscious emotion experience (LeDoux, 2020).

In contrast, exposure to body odors produced in disgust activating contexts triggers a *sensory rejection* state (Susskind et al., 2008), characterized by activation of the *levator labii superioris* muscle and psychophysiological reactions such as a decrease in sniff magnitude (de Groot et al., 2012). Functionally, and akin to fear, disgust chemosignals provide a connection between the donor and receiver to share a preparedness to avoid potential sources of harm. As suggested by a recent study, disgust body odors play a major role in shaping our food choices (even outperforming disgust visual cues in certain circumstances), facilitating food healthiness decisions (Zheng et al., 2018).

A small number of studies have so far investigated the effects of chemosignals on the visual sensory system, and their results differ depending on the type of experimental procedure used. For example, fear chemosignals facilitate specifically the conscious categorization of odor-congruent facial expressions of fear (Kamiloğlu et al., 2018; Zhou & Chen, 2009). Other studies (Rubin et al., 2012), however, suggest that fear-related chemosignals might instead augment attention to all stimuli, regardless of their emotion value (i.e., attention to otherwise innocuous stimuli is increased). Some studies (e.g., Zernecke et al., 2011) even show that the positive valence of a facial expression is reduced under exposure to anxiety sweat (but see Pause, 2004). However, in a different study, fear chemosignals have been shown to facilitate the detection of different facial expressions in addition to fear. Using breaking Continuous Flash Suppression (b-CFS; Jiang et al., 2007) – a technique that momentarily suppresses a visual stimulus from visual awareness, de Groot and colleagues (2018) showed that exposure to fear body odor lowers the threshold of visual detection (i.e., quicker access to awareness) of *all* types of facial expressions (happy, fear and neutral) that were presented. In contrast, happy body odors facilitated the detection of only the odor-congruent facial expression.

In this study, we examined how access to awareness of neutral and emotional (fear, disgust) facial expressions is modulated by fear and disgust chemosignals. Faces were shown under visually competing conditions in a variant of the binocular rivalry paradigm (i.e., b-CFS). Access to awareness was measured by the latency of conscious detection. Earlier studies suggested that, based on the type of emotional chemosignals present different types of facilitation effects can be expected, namely either emotion-specific or generalized processing of facial expressions. The only study that used b-CFS in this type of experimental context (see de Groot et al., 2018),

however, showed that fear chemosignals result in faster awareness of all facial expressions (fear, happy and neutral). On the basis of this study one would expect all facial expressions (disgust, fear, neutral) to reach awareness faster when exposed to fear odor. In contrast, in an earlier study with a different methodology, Kamiloğlu and her colleagues (2018) reported that fear chemosignals were shown to facilitate only fear odor-congruent facial expressions when exposed to facial images of anger, fear, disgust and neutral expressions. Nonetheless, given that this study more closely resembles de Groot and colleagues' (2018) methodology, we posited that fear odor will facilitate access to awareness to all facial expressions.

As for the new body odor introduced here (i.e., disgust), based on evidence suggesting that this state has an opposite effect to fear – inducing a generalized state of sensory rejection (de Groot et al., 2012; Susskind et al., 2008) we expected disgust body odor to increase time under suppression across all facial expressions.

Method

Odor donors

Participants. Odor samples were collected from a total of eight Caucasian male participants, aged between 18 and 35 years ($M = 22.5$, $SD = 2.1$). In line with previous research (e.g., de Groot et al., 2012) axillary sweat was collected only from male participants (given their larger apocrine glands; Doty et al., 1978). Every participant reported being heterosexual, healthy and non-smoker, having no past or current psychological disorders and not taking any current medication.

Procedure. Neutral and emotional states of fear and disgust were induced through videos (composed of several smaller video clips with a total average duration of 25 minutes), based on a pilot study ($N=58$). Namely, the fearful condition was composed of several horror movies (scary clips of known horror movies), the disgust condition involved several scenes depicting aversive food, bugs or human secretions and the neutral condition was composed by several nature/animal-related documentaries plus nature sceneries. Participants were presented with these videos in a closed and controlled room, while wearing pads under their armpits.

Odor collections were separated by a week's interval, with participants following a strict behavioral and dietary regimen every two days prior to each odor collection to avoid sweat contamination (see de Groot et al., 2012 for a detailed list of restrictions). A descriptive look at post video emotional ratings showed that, when compared to the

other emotion-inducing conditions, participants were feeling, on average, more fearful with the fear inducing videos and more disgust with the disgust inducing videos. They also experienced reduced states of fear/disgust (contrasting with high ratings of neutral) with the neutral-inducing videos (see Appendix A for further details on the ratings and a statistical analysis).

Odor Receivers

Participants and design. A total of 32 female participants were recruited from our lab's participant pool. In line with previous studies (e.g., Zhou & Chen, 2009), only females were tested due to their better sense of smell (Brand & Millot, 2001) and increased sensitivity to emotional odor signals (de Groot et al., 2014). Three participants were excluded: one due to frequently losing binocular fusion, one due to somnolence and a third one for disclosing a psychiatric disorder at the end of the experiment. A total of 29 participants were included in the final analysis (age $M = 24$, $SD = 4.5$). A power analysis (G*Power 3.1.9.2; Faul et al., 2007) for a repeated-measures analysis of variance (ANOVA; $\eta^2_p = .08$, power = .80, $\alpha = .05$), based on an effect size obtained in a prior similar study (i.e., de Groot et al., 2018), yielded a minimum sample size of 24 participants. We, nonetheless, recruited the number of participants mentioned above (32) since our odor samples were enough for this number and also to account for possible participant exclusions later on the analysis. Additional criteria for inclusion were right-handedness, being heterosexual (see Martins et al., 2005) and nonsmoker, not being pregnant, and not having a record of major psychological or neurological disorder, nor suffering from current respiratory disease (illness, cold or allergy). Participants provided informed consent and received a reward for their participation (course credits or 10€). The study was approved by the ethics committee of the host institution and was conducted in accordance with the standards of the American Psychological Association and the guidelines of the Declaration of Helsinki (World Medical Association, 2013). The study followed a three (Odor: Fear, Disgust and Neutral) by three (Facial Expression: Fear, Disgust and Neutral) within-subjects design.

Apparatus & Stimuli. The odor stimuli were prepared with the sweat pads collected earlier from donors. The pads (10 by 10 cm) were each cut into eight equally sized parts and randomly distributed into individual vials (four per vial with two parts from the left and two parts from the right armpit), with each vial representing a condition and assigned to a participant. To avoid effects of inter-individual variability, the four

pad pieces that composed each vial came from different donors. In addition, the same donors composed all three (fear, disgust and neutral) conditions for each participant. A total of 18 faces (nine men) depicting fear, disgust and neutral emotional expressions (six per condition) were chosen from the Radboud Faces Database (Langner et al., 2010). A larger initial set was collected from the database and using GIMP (version 2.10.8) images were converted to grayscale and overlaid with an oval mask hiding hair and background (1:2 width to height ratio). All faces occupied an identical area of the picture. The stimuli were then scaled to an area of 300 by 450 pixels. Using a custom-made Matlab script, luminosity, root-mean-square contrast and power spectrum values (across eight bands) of each image were extracted. A One-Way ANOVA comparing emotional conditions was performed for each of these features. The final set of images was chosen from those that showed no differences across all spatial frequency bands ($p > .05$ in all cases), luminosity and contrast between emotional conditions (see Appendix B). Final images covered 3 x 4.5 degrees of visual angle (Fig. 1).

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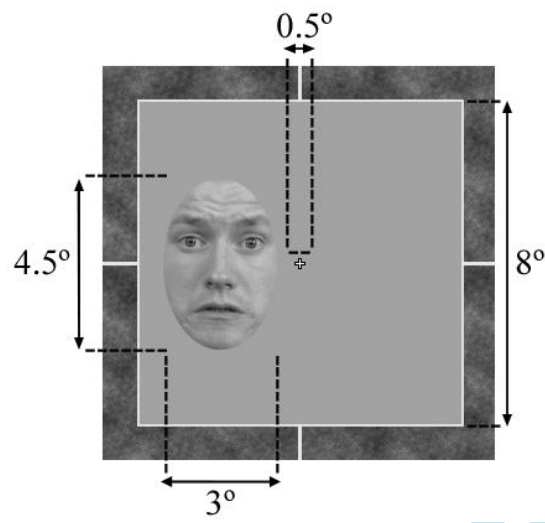


Figure 1. Dimensions of stimuli. The interior of the square (not counting the noise border) was 8° by 8°. Facial expressions were 3° by 4.5°. The central cross was 0.5° by 0.5°.

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The experimental task and contrast adjustment (see below for details) were programmed with Psychopy (version 3.1; Peirce et al., 2019), and presented on a 1920 x 1080 pixels computer screen. To measure the speed at which participants became aware of the emotional expressions (i.e., when they broke suppression), we used b-CFS paradigm (Jiang et al., 2007). This technique was implemented with the use of a mirror stereoscope (custom built²) and a head-chin rest. This device allows the participants to view the left half of the screen with their left eye and the right half with their right eye. Each individual mirror of the mirror stereoscope was adjusted to allow perfect binocular fusion for each individual. To secure the odor samples, a flexible clamp was used to hold the vials under the participants' nose at a distance of around 4 cm.

Electromyography (EMG). Facial EMG was used to assess participants' facial muscle activity during their exposure to each odor. Surface electrodes (Ag-AgCl) were placed following standard guidelines (Fridlund & Cacioppo, 1986) over the left *medial frontalis* and the *levator labii superioris* muscles, which are typically activated respectively in expressions of fear and disgust (Ekman et al., 1981). Participant's skin was cleaned with an abrasive skin lotion (Lemon Prep; Mavidon, Lake Worth, FL) prior to the attachment of the electrodes. EMG data were collected with low-pass and high-pass filters of 20 Hz and 200 Hz, respectively, and with a 1000 Hz sampling rate.

Procedure. Odor vials were thawed for one hour prior to participants' arrival. Upon arriving at the lab, participants provided informed consent, and some basic sociodemographic data. They then filled out a questionnaire regarding their current and usual anxiety levels (STAI; Silva & Spielberger, 2007; Spielberger et al., 1970). A Portuguese version of the Edinburgh Handedness Inventory (Espírito-Santo et al., 2017; Oldfield, 1971) was used to ensure that all participants were right-handed.

The Miles test (Miles, 1930) was used to assess participants' ocular dominance, followed by the placement of EMG electrodes. Participants' head was positioned on the chin rest, with their eyes around 50 cm away from the center of the screen. After the

²The custom build mirror stereoscope used in this study is based on version 2 of an example found in the following website: <http://www.psy.vanderbilt.edu/faculty/blake/Stereoscope/stereoscope.html>

calibration of the mirror stereoscope, a contrast adjustment task was introduced, controlling for between-subject variability in CFS thresholds (average suppression duration; Yamashiro et al., 2014). As a measure to adjust contrast to each individual (contrast adjustment task), participants were presented with a close replica of the experimental task where faces (only neutral expressions) were presented in one of the sides of the central cross (no fade-ins or fade-outs, totaling seven seconds of trial, for 24 trials). They were instructed to indicate the left/right position of the face, with respect to the central fixation cross, by pressing “z” or “m” (respectively) on a QWERTY computer keyboard. They were told to do so the moment they saw a face or any other visual element that would suggest the presence of a face, whilst maintaining their gaze on the central cross. In each trial, flashing colorful patches were presented to the dominant eye, immediately followed by a face presented to the non-dominant eye. The contrast of the face started at 5%, and would either increase or decrease by 5% in each trial, based on participant’s face awareness in the previous trial (see Rothkirch & Hesselmann, 2018). This allowed to define the highest level of contrast possible without awareness for each participant, which was then employed in the experimental task.

Just before initiating the main task, participants were reminded of the instructions (described in the previous paragraph) and performed a brief practice block (12 trials; see below for trial description). Once they finished the practice block, the first vial was placed on the clamp, holding it just below the participant’s nose (at about 4 cm) throughout the block. Participants were told to ignore the vial and focus on the task at hand. A nose clip was then applied to the participant’s nose, preventing preliminary sniffs when the vial was opened. The vial was opened, and the nose clip was removed at the same moment as the block started, and participants were presented with a blank screen for five seconds (during which EMG data were collected) followed by the normal initiation of the task.

In the main task (as with the training block), each trial lasted a total of seven seconds, with the Mondrian mask first appearing after one second (with a previous 0.2 s fade-in), followed immediately by the face stimulus slowly increasing in contrast (one-second fade-in). The face and Mondrian mask remained at full contrast for one second and then the mask started to decrease in contrast over a three second period. When the mask disappeared, the face would fade-out over one second. The inter-trial-interval was one

second (see Figure 2 for a full representation of a trial). Each participant completed three blocks with 72 trials each (216 trials in total), with a five-minute interval between blocks, to allow for the preceding odor to dissipate (washout period). Odor presentation order was counterbalanced between participants and facial expressions were presented randomly throughout each block.

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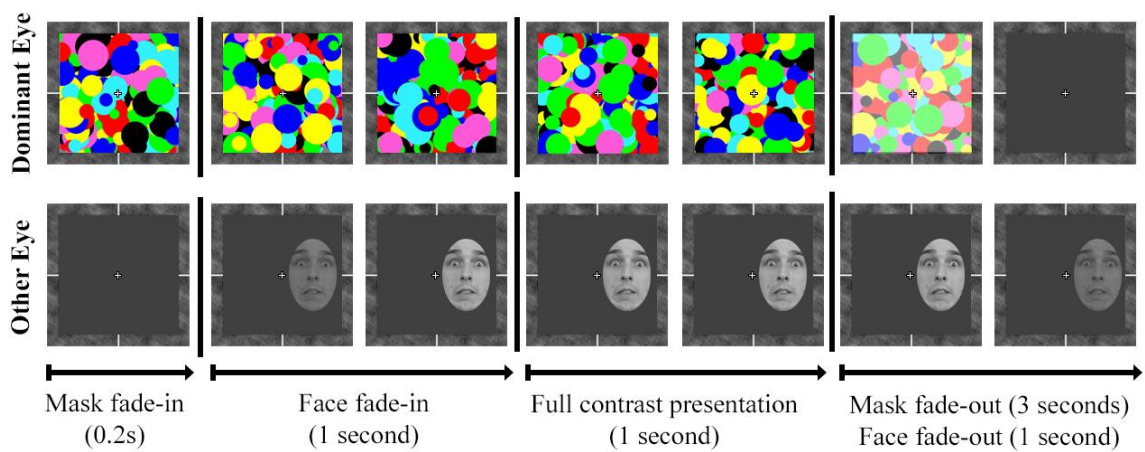


Figure 2. Progression of a trial. A blank screen (with only the fixation cross) was present for 0.8 s. Next, the Mondrian mask was presented (with 0.2 s of fade-in), followed by a stimulus (face) ramping-up in contrast (over 1 s). Both stimulus and Mondrian mask were presented at full contrast for 1 s. Finally, the Mondrian mask decreased in contrast over 3 s. At the end of this period, the face would fade-out over 1 s, ending the trial.

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At the end of the experimental task, the EMG electrodes were removed, and the participants completed a hedonic and intensity evaluation of the odor samples used during the experimental task, rating the pleasantness and intensity of each odor on a Likert scale (one to seven, with one being not pleasant and seven being extremely pleasant). An additional odor discrimination task, similar to the one used in de Groot, Semin, & Smeets (2014), was used to evaluate participants' ability to discriminate the different odors. In this task, participants were presented with an initial reference sweat sample and then with all the sweat samples used in the main experimental task. They were told to identify, which of the odors was the initially presented reference sweat. This was done once for each sweat condition (fear, disgust and neutral), with the presentation order counterbalanced across all participants. To rule out anosmia, participants were also subjected to a simple odor identification test (based on Lötsch et al., 2016), where they were asked to identify odors of cinnamon, fish, and banana using sniffing sticks. Lastly, participants answered three brief questions that assessed their awareness of the task's purpose and contents of the vials.

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Statistical analysis

EMG data of the 4.6 s of odor exposure at the beginning of each block was full-wave rectified, filtered with a 50 Hz notch, and smoothed with a 20 Hz low-pass filter using the software EMG Analysis (3.1.5; MindWare Technologies, Gahanna, OH). The first 600 ms following the removal of the nose clip were used as a baseline, since the first sniff typically occurs after 400 ms (Sela & Sobel, 2010). Similarly to Kamiloğlu and colleagues (2018), the final signal was averaged into 50 ms intervals for an artifact removal based on 2.5 median absolute deviation criteria (Leys et al., 2013) and linearly interpolated using the R package “Zoo” (Zeileis & Grothendieck, 2005; percentages of interpolation detailed in Appendix C). Data were then averaged into 200 ms intervals and corrected for baseline (the mean of the baseline was subtracted from each individual 200 ms interval of the remaining 4000 ms). Outliers were identified and removed using the same method as the artifact removal (see Appendix D), with the exceeding values being replaced by values one unit above the next extreme score on that variable (according to Field, 2009). Participants with percentages of outlier data above 75% were excluded from the final analysis (one participant removed from the *medial frontalis* analysis and one in the *levator labii superioris*). Finally, the signal was averaged into four one-second intervals (covering the 600 – 4600 ms period after the opening of the nose clip). For each muscle, activation was analyzed with a repeated measure analysis of variance (rmANOVA), with the factors Time (four intervals) and Odor (Fear, Disgust, Neutral) as within-subjects variables. Any lack of sphericity in the rmANOVA was adjusted with Greenhouse–Geisser corrections.

Only response times (RTs) concerning correct responses were analyzed. Additionally, RTs faster than 500 ms (indicating no initial suppression) or slower than 5 s (Mondrian mask at 0% contrast) after the face started to fade-in were removed and winsorized to those respective limits. RTs were analyzed with a rmANOVA, with Odor (Fear, Disgust and Neutral) and Facial Expression (Fear, Disgust and Neutral) as within-subject factors. Post-hoc tests were performed with Bonferroni corrections.

Regarding the self-reported measures of pleasantness and intensity, since the data did not present a normal distribution, we performed non-parametric Friedman tests to examine for possible differences in these variables between conditions.

Results

EMG

For the *medial frontalis* muscle, a 3 Odor by 4 Time rmANOVA did not reveal a significant main effect of Odor ($F(2, 56) = .368, p = .694, \eta^2_p = .013$), of Time ($F(1.733, 48.529) = .353, p = .674, \eta^2_p = .012$), nor a significant Odor by Time interaction ($F(4.465, 125.016) = .500, p = .756, \eta^2_p = .018$). Similarly, the analysis for the *levator labii superioris* muscle, did not show evidence for a significant main effect of Odor ($F(2, 52) = .939, p = .397, \eta^2_p = .035$), nor for a significant interaction between Odor and Time ($F(3.329, 86.555) = 1.192, p = .319, \eta^2_p = .044$). However, the analysis on this muscle showed a main effect of Time ($F(1.774, 46.121) = 10.683, p < .001, \eta^2_p = .291$).

Behavioral data

Analysis of RTs did not reveal a main effect of Odor ($F(2,56) = .619, p = .542, \eta^2_p = .019$)³, but a main effect of facial expression ($F(1.318,56) = 19.982, p < .001, \eta^2_p = .416$), as well as an Odor by Facial Expression interaction ($F(4,112) = 2.872, p = .026, \eta^2_p = .093$). For the main effect of facial expression, post-hoc tests showed that disgust faces were on average slower to break suppression than fearful ($t(56) = 6.27, p < .001, d = 1.164$) and neutral faces ($t(56) = 3.84, p < .001, d = 0.713$), irrespective of odor condition. Additionally, fear faces were also faster to break suppression than neutral faces ($t(56) = -4.055, p = .001, d = -0.753$). However, the Odor by Facial Expression interaction, showed that fear faces were only faster on average to break suppression than neutral faces in the fear odor condition ($t(128.2) = -3.753, p = .008, d = -0.697$), with no differences being observed in the neutral and disgust odor condition ($p > .05$; see Figure 3). The Odor by Facial Expression interaction remained significant when adding trait-anxiety as a covariate⁴ ($F(4,108) = 3.070, p = .019, \eta^2_p = .102$).

³ To check for a vigilance effect, we further conducted a planned contrast analysis comparing the general effects of Fear Odor against Disgust and Neutral Odors combined, revealing no differences between these two conditions ($F(1, 28) = .279, p = .601, \eta^2_p = .010$). We also performed a Bayesian t-test contrasting these same two variables, which showed a strong support for the null hypothesis ($BF_{01} = 4.454 \pm 4.708e-4$).

⁴ The addition of the covariate in the analysis followed the findings by Capitão and colleagues (2014), showing that anxiety increases the breakthrough of threat stimuli in b-CFS paradigms.

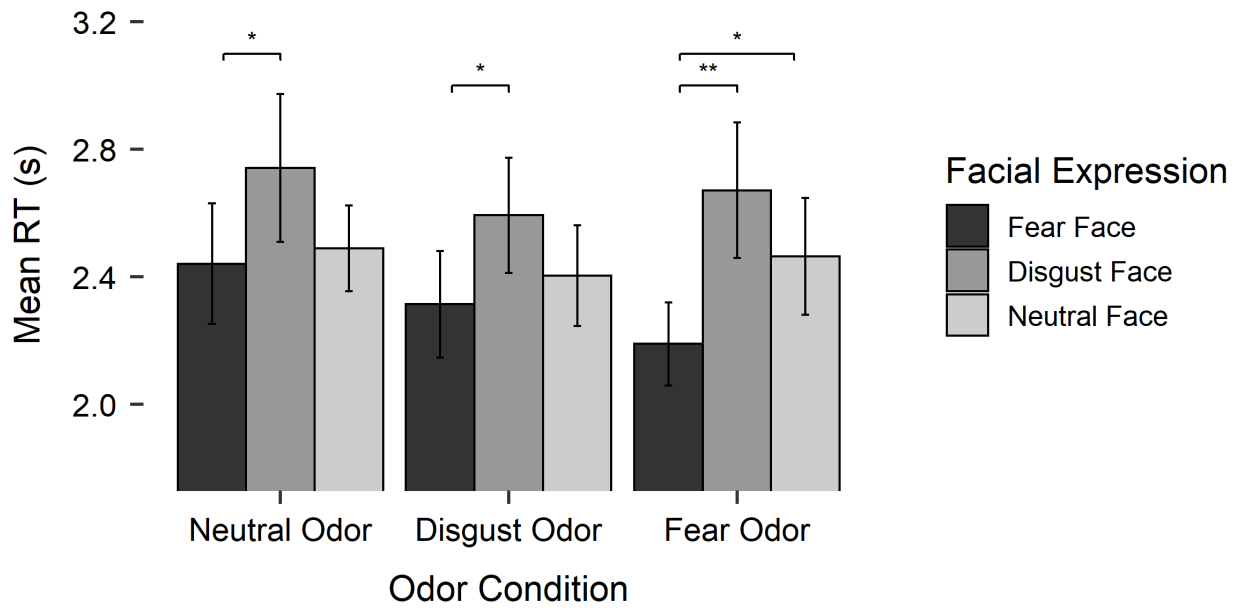


Figure 3. Mean access to awareness times per odor condition and emotional expression. Error bars represent 95% CI.
 * $p < .05$; ** $p < .001$

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Intensity and pleasantness evaluation tasks were analyzed with a non-parametric Friedman test of differences among repeated measures (see Appendix E). This test revealed no statistically significant differences between the three odor conditions (fear, disgust, and neutral stimuli) in self-reported intensity ($\chi^2(2) = .88$; $p = .655$) and pleasantness ($\chi^2(2) = 5.68$; $p = .059$). Lastly, binomial tests showed that participants could not discriminate among fear (proportion under the null hypothesis = .33, $p = .233$), disgust (proportion under the null hypothesis = .33, $p = .135$), and neutral (proportion under the null hypothesis = .33, $p = .063$) sweat stimuli.

Discussion

The goal of this study was to explore how exposure to body odors that were collected under emotional and neutral states affect the visual processing of emotional (and neutral) facial expressions. As such, we explored how these emotional odors altered the time interval that different facial expressions took to reach visual awareness during CFS (i.e., breaking-CFS; Jiang et al., 2007). Importantly, we focused on fear, whilst using a second negative emotion, i.e., disgust, to assert how previously shown fear odor effects on visual processing (vigilance effect; de Groot et al., 2018) might be unique and distinct to this emotion.

The results showed that, indeed, emotional sweat significantly affected how quickly facial expressions broke CFS. However, these effects were only observed for the fear odor, and not the disgust odor. Moreover, fear odor did not, contrary to what we initially hypothesized, demonstrate a general vigilance effect, prompting instead a lower awareness threshold specifically to congruent (i.e., fear) facial expressions. These findings go directly against the conclusions drawn by de Groot and colleagues (2018), who stated that fear should reduce awareness thresholds for all facial expressions, including neutral ones.

To explain the lack of a generalized effect (or vigilance effect) of fear odor on visual processing of facial expressions, it is important to describe the expected neural changes induced by fear on visual processing mechanisms. Fear contexts (induced by emotion primers such as facial expressions) can modulate early stages of visual processing. For example, fear states can bias early vision towards an enhanced processing of low-spatial frequencies (LSFs; i.e., gross/coarse visual information), to the detriment of high-spatial frequencies (HSFs; fine details; Bocanegra & Zeelenberg, 2009; Nicol et al., 2013). This effect on low-level vision is thought to depend on amygdala activation

with subsequent neuromodulation of the visual cortex by the amygdala (Phelps et al., 2006). Importantly, increased amygdala responses to fearful faces depend predominantly on LSF features, and occur after as little as 74 ms (Méndez-Bértolo et al., 2016; Vuilleumier et al., 2003). One could thus posit that a fear state induced by fear odors might have biased vision towards LSF features, which reduced suppression times to fear faces more pronouncedly given their innate capacity to be recognized more rapidly via LSF features alone.

The absence of effects in the disgust odor condition compared to the effects observed in the fear condition prompts another relevant conclusion. When compared to other negative emotion odors (in this case disgust), fear odors appear to have the unique ability to alter how visual processing mechanisms work, favoring the processing of danger-signaling cues (in this case fearful facial expressions). Disgust odors, on the other hand, did not evoke any changes in visual processing that reflected themselves in the times facial expressions took to reach awareness. This goes against our initial hypothesis which, based on prior literature (e.g., Krusemark & Li, 2011), suggested opposite effects for fear and disgust odors, i.e. disgust odors were expected to slow down access to awareness, while fear odors were expected to speed it up. It is possible that, at this early stage of visual processing that is being measured in b-CFS paradigms – where no high-level or complex processing is thought to occur (Peremen & Lamy, 2014) –, emotion, at least when triggered via body odors, might have limited capabilities. Fear odor, however, given its evolutionary relevance as a means of alerting for danger (Öhman, 2009) occupies a different function compared to other types of emotions. This is also supported by the aforementioned arguments regarding spatial frequencies and the amygdala. Fear odor would therefore be critical in enabling the receiver with quicker defensive responses by promoting a perceptual preparedness mechanism in threat situations. Importantly, this is still hard to determine, especially considering the findings of de Groot et al (2018) that showed a congruency effect of happy odors to happy expressions.

Although rather speculative and considering that in this study we approach the states evoked by the body odors as functional emotional states and not necessarily as emotions, the current results also seem to be in line with a categorical approach to emotion as opposed to a dimensional view. In the former, emotions are discrete and have a unique innate neural substrate (Murphy, Nimmo-Smith, & Lawrence, 2003),

thus postulating unique fingerprints for each “basic” emotion. The dimensional view, on the other hand, claims that no such boundaries between emotional states exist (Barrett, 2006; Lindquist et al., 2012). Instead, the dimensional view assumes an initial evaluation (positive and negative) and activation dimensions, with later top-down knowledge interacting with sensory input, giving meaning to the emotion and turning this state into a discrete event (e.g., anger vs. sadness; Barrett, 2006; Panksepp, 2007). When considering both theories, our results – alongside similar prior work using body odors (Kamiloglu et al., 2018) – appear to favor a categorial approach to emotions, where fear odor cues target the processing of fear faces uniquely even at early stages of visual processing – without conscious top-down knowledge. Regardless, this remains but a thought-provoking idea for future studies to consider.

Our intended manipulation check, i.e. the EMG analysis, did not reveal the expected pattern of facial muscle activation that follows when exposed to each emotion odor. Upon initial inspection of the data, an elevated artifact contamination of the baselines (around 19% of the values were categorized as artifacts) is thought to have contributed to the lack of any odor-specific EMG effects. This, we believe, might have led to a distortion of the baseline, thus precluding accurate corrections and subsequently any valid comparisons between odor conditions and muscle activation. The lack of EMG responses to the odors suggests that the behavioral findings should be interpreted with care.

Following the discussion of the observed findings, future studies should look into manipulating spatial frequencies of the facial expressions so as to possibly disentangle the drivers of the effects described here. Additionally, menstrual cycles should be controlled in future studies, so as to assure that this does not play a role of a confounding variable. An important, perhaps limiting factor of the current study, that should also be considered in future research, is the use of videos as a mean to induce emotions in participants. As observed by their post-video ratings, this method might not be the best nor most reliable. A further control measure that might have played a role here is odor habituation, which, although research has pointed that social body odors appear less prone to habituation (McClintock, 2002) with contextual effects lasting for long durations (de Groot et al., 2012), could still be controlled in future investigations. Still regarding habituation, as done by some other studies (e.g., Zheng et al., 2018), instructing participants to inhale at the beginning of each trial might have perhaps also

augmented the results, and thus could be considered in future investigations. Lastly, since this study was limited to the visual sensory modality, exploring how other modalities, such as sound (e.g., voice) emotional cues are processed under exposure of fear and disgust body odors might help to understand how emotional body odors interact with sensory processing in general.

In sum, our results support the idea that fear chemosignals have a significant impact in our visual processes. Namely, fear odor provides a contextual cue that favors a quicker access to awareness of corresponding fearful faces. Since similar findings could not be observed for disgust, this suggests a unique attribute of fear in providing contextual cues for fear facial expression processing, perhaps due to its evolutionary role as a danger alert system. More research is required, however, to further explore the specificity of the effects that fear chemosignals have on the processing of other fear-related stimuli.

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References

- Adolphs, R., & Andler, D. (2018). Investigating Emotions as Functional States Distinct From Feelings. *Emotion Review*, 10(3), 191–201. <https://doi.org/10.1177/1754073918765662>
- Barrett, L. F. (2006). Are Emotions Natural Kinds? *Perspectives on Psychological Science*, 1(1), 28–58. <https://doi.org/10.1111/j.1745-6916.2006.00003.x>
- Bocanegra, B. R., & Zeelenberg, R. (2009). Emotion Improves and Impairs Early Vision. *Psychological Science*, 20(6), 707–713. <https://doi.org/10.1111/j.1467-9280.2009.02354.x>
- Brand, G., & Millot, J.-L. (2001). Sex differences in human olfaction: Between evidence and enigma. *The Quarterly Journal of Experimental Psychology B*, 54(3), 259–270. <https://doi.org/10.1080/02724990143000045>
- Capitão, L. P., Underdown, S. J. V., Vile, S., Yang, E., Harmer, C. J., & Murphy, S. E. (2014). Anxiety increases breakthrough of threat stimuli in continuous flash suppression. *Emotion*, 14(6), 1027–1036. <https://doi.org/10.1037/a0037801>
- de Groot, J. H. B., Semin, G. R., & Smeets, M. A. M. (2014). Chemical communication of fear: A case of male–female asymmetry. *Journal of Experimental Psychology: General*, 143(4), 1515–1525. <https://doi.org/10.1037/a0035950>
- de Groot, J. H. B., Smeets, M. A. M., Kaldewaij, A., Duijndam, M. J. A., & Semin, G. R. (2012). Chemosignals Communicate Human Emotions. *Psychological Science*, 23(11), 1417–1424. <https://doi.org/10.1177/0956797612445317>
- de Groot, J. H. B., van Houtum, L. A. E. M., Gortemaker, I., Ye, Y., Chen, W., Zhou, W., & Smeets, M. A. M. (2018). Beyond the West: Chemosignaling of Emotions Transcends Ethno-Cultural Boundaries. *Psychoneuroendocrinology*, 98, 177–185. <https://doi.org/10.1016/j.psyneuen.2018.08.005>
- Doty, R. L., Orndorff, M. M., Leyden, J., & Kligman, A. (1978). Communication of gender from human axillary odors: Relationship to perceived intensity and hedonicity. *Behavioral Biology*, 23(3), 373–380. [https://doi.org/10.1016/S0091-6773\(78\)91393-7](https://doi.org/10.1016/S0091-6773(78)91393-7)
- Ekman, P., Hager, J. C., & Friesen, W. V. (1981). The Symmetry of Emotional and Deliberate Facial Actions. *Psychophysiology*, 18(2), 101–106. <https://doi.org/10.1111/j.1469-8986.1981.tb02919.x>
- Espírito-Santo, H., Pires, C. F., Garcia, I. Q., Daniel, F., Silva, A. G. da, & Fazio, R. L. (2017). Preliminary validation of the Portuguese Edinburgh Handedness Inventory in an adult sample. *Applied Neuropsychology: Adult*, 24(3), 275–287. <https://doi.org/10.1080/23279095.2017.1290636>
- Faul, F., Erdfelder, E., Lang, A.-G., & Buchner, A. (2007). G*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods*, 39(2), 175–191. <https://doi.org/10.3758/BF03193146>
- Field, A. (2009). *Discovering statistics using SPSS*. Sage publications.
- Fridlund, A. J., & Cacioppo, J. T. (1986). Guidelines for human electromyographic research. *Psychophysiology*, 23(5), 567–589.

- Jacob, S., McClintock, M. K., Zelano, B., & Ober, C. (2002). Paternally inherited HLA alleles are associated with women's choice of male odor. *Nature Genetics*, *30*(2), 175–179. <https://doi.org/10.1038/ng830>
- Jiang, Y., Costello, P., & He, S. (2007). Processing of Invisible Stimuli: Advantage of Upright Faces and Recognizable Words in Overcoming Interocular Suppression. *Psychological Science*, *18*(4), 349–355. <https://doi.org/10.1111/j.1467-9280.2007.01902.x>
- Kamiloğlu, R. G., Smeets, M., de Groot, J. H. B., & Semin, G. R. (2018). Fear Odor Facilitates the Detection of Fear Expressions over other Negative Expressions. *Chemical Senses*, *43*, 419–426. <https://doi.org/10.1093/chemse/bjy029>
- Krusemark, E. A., & Li, W. (2011). Do All Threats Work the Same Way? Divergent Effects of Fear and Disgust on Sensory Perception and Attention. *Journal of Neuroscience*, *31*(9), 3429–3434. <https://doi.org/10.1523/JNEUROSCI.4394-10.2011>
- Langner, O., Dotsch, R., Bijlstra, G., Wigboldus, D. H. J., Hawk, S. T., & van Knippenberg, A. (2010). Presentation and validation of the Radboud Faces Database. *Cognition & Emotion*, *24*(8), 1377–1388. <https://doi.org/10.1080/02699930903485076>
- LeDoux, J. E. (2020). Thoughtful feelings. *Current Biology*, *30*(11), R619–R623. <https://doi.org/10.1016/j.cub.2020.04.012>
- Leys, C., Ley, C., Klein, O., Bernard, P., & Licata, L. (2013). Detecting outliers: Do not use standard deviation around the mean, use absolute deviation around the median. *Journal of Experimental Social Psychology*, *49*(4), 764–766. <https://doi.org/10.1016/j.jesp.2013.03.013>
- Lindquist, K. A., Wager, T. D., Kober, H., Bliss-Moreau, E., & Barrett, L. F. (2012). The brain basis of emotion: A meta-analytic review. *Behavioral and Brain Sciences*, *35*(03), 121–143. <https://doi.org/10.1017/S0140525X11000446>
- Lötsch, J., Ultsch, A., & Hummel, T. (2016). How Many and Which Odor Identification Items Are Needed to Establish Normal Olfactory Function? *Chemical Senses*, *41*(4), 339–344. <https://doi.org/10.1093/chemse/bjw006>
- Martins, Y., Preti, G., Crabtree, C. R., Runyan, T., Vainius, A. A., & Wysocki, C. J. (2005). Preference for Human Body Odors Is Influenced by Gender and Sexual Orientation. *Psychological Science*, *16*(9), 694–701. <https://doi.org/10.1111/j.1467-9280.2005.01598.x>
- McClintock, M. K. (2002). Pheromones, odors, and vasanas: The neuroendocrinology of social chemosignals in humans and animals. In *Hormones, Brain & Behavior* (Pfaff D, Arnold A, Etgen A, Rubin R, Fahrbach S, pp. 797–870). San Diego: Academic Press.
- Méndez-Bértolo, C., Moratti, S., Toledano, R., Lopez-Sosa, F., Martínez-Alvarez, R., Mah, Y. H., Vuilleumier, P., Gil-Nagel, A., & Strange, B. A. (2016). A fast pathway for fear in human amygdala. *Nature Neuroscience*. <https://doi.org/10.1038/nn.4324>
- Miles, W. R. (1930). Ocular Dominance in Human Adults. *The Journal of General Psychology*, *3*(3), 412–430. <https://doi.org/10.1080/00221309.1930.9918218>

- Mitro, S., Gordon, A. R., Olsson, M. J., & Lundström, J. N. (2012). The Smell of Age: Perception and Discrimination of Body Odors of Different Ages. *PLoS ONE*, 7(5), e38110. <https://doi.org/10.1371/journal.pone.0038110>
- Mujica-Parodi, L. R., Strey, H., Frederick, B., Savoy, R., Cox, D., Botanov, Y., Tolkunov, D., Rubin, D., & Weber, J. (2008). Second-Hand Stress: Neurobiological Evidence for a Human Alarm Pheromone. *Nature Precedings*. <https://doi.org/10.1038/npre.2008.2561.1>
- Mujica-Parodi, L. R., Strey, H. H., Frederick, B., Savoy, R., Cox, D., Botanov, Y., Tolkunov, D., Rubin, D., & Weber, J. (2009). Chemosensory Cues to Conspecific Emotional Stress Activate Amygdala in Humans. *PLoS ONE*, 4(7), e6415. <https://doi.org/10.1371/journal.pone.0006415>
- Murphy, F. C., Nimmo-Smith, I., & Lawrence, A. D. (2003). Functional neuroanatomy of emotions: A meta-analysis. *Cognitive, Affective, & Behavioral Neuroscience*, 3(3), 207–233. <https://doi.org/10.3758/CABN.3.3.207>
- Mutic, S., Parma, V., Brünner, Y. F., & Freiherr, J. (2016). You Smell Dangerous: Communicating Fight Responses Through Human Chemosignals of Aggression. *Chemical Senses*, 41(1), 35–43. <https://doi.org/10.1093/chemse/bjv058>
- Nicol, J. R., Perrotta, S., Caliciuri, S., & Wachowiak, M. P. (2013). Emotion-specific modulation of early visual perception. *Cognition & Emotion*, 27(8), 1478–1485. <https://doi.org/10.1080/02699931.2013.793654>
- Öhman, A. (2009). Of snakes and faces: An evolutionary perspective on the psychology of fear. *Scandinavian Journal of Psychology*, 50(6), 543–552. <https://doi.org/10.1111/j.1467-9450.2009.00784.x>
- Oldfield, R. C. (1971). The assessment and analysis of handedness: The Edinburgh inventory. *Neuropsychologia*, 9(1), 97–113. [https://doi.org/10.1016/0028-3932\(71\)90067-4](https://doi.org/10.1016/0028-3932(71)90067-4)
- Olsson, M. J., Lundström, J. N., Kimball, B. A., Gordon, A. R., Karshikoff, B., Hosseini, N., Sorjonen, K., Olgart Höglund, C., Solares, C., Soop, A., Axelsson, J., & Lekander, M. (2014). The Scent of Disease: Human Body Odor Contains an Early Chemosensory Cue of Sickness. *Psychological Science*, 25(3), 817–823. <https://doi.org/10.1177/0956797613515681>
- Panksepp, J. (2007). Neurologizing the Psychology of Affects: How Appraisal-Based Constructivism and Basic Emotion Theory Can Coexist. *Perspectives on Psychological Science*, 2(3), 281–296. <https://doi.org/10.1111/j.1745-6916.2007.00045.x>
- Pause, B. M. (2004). Positive Emotional Priming of Facial Affect Perception in Females is Diminished by Chemosensory Anxiety Signals. *Chemical Senses*, 29(9), 797–805. <https://doi.org/10.1093/chemse/bjh245>
- Peirce, J., Gray, J. R., Simpson, S., MacAskill, M., Höchenberger, R., Sogo, H., Kastman, E., & Lindeløv, J. K. (2019). PsychoPy2: Experiments in behavior made easy. *Behavior Research Methods*, 51(1), 195–203. <https://doi.org/10.3758/s13428-018-01193-y>

- Penn, D. J., Oberzaucher, E., Grammer, K., Fischer, G., Soini, H. A., Wiesler, D., Novotny, M. V., Dixon, S. J., Xu, Y., & Brereton, R. G. (2007). Individual and gender fingerprints in human body odour. *Journal of The Royal Society Interface*, 4(13), 331–340. <https://doi.org/10.1098/rsif.2006.0182>
- Peremen, Z., & Lamy, D. (2014). Comparing unconscious processing during continuous flash suppression and meta-contrast masking just under the limen of consciousness. *Frontiers in Psychology*, 5. <https://doi.org/10.3389/fpsyg.2014.00969>
- Phelps, E. A., Ling, S., & Carrasco, M. (2006). Emotion Facilitates Perception and Potentiates the Perceptual Benefits of Attention. *Psychological Science*, 17(4), 292–299. <https://doi.org/10.1111/j.1467-9280.2006.01701.x>
- Prehn, A., Ohrt, A., Sojka, B., Ferstl, R., & Pause, B. M. (2006). Chemosensory anxiety signals augment the startle reflex in humans. *Neuroscience Letters*, 394(2), 127–130. <https://doi.org/10.1016/j.neulet.2005.10.012>
- Prehn-Kristensen, A., Wiesner, C., Bergmann, T. O., Wolff, S., Jansen, O., Mehdorn, H. M., Ferstl, R., & Pause, B. M. (2009). Induction of Empathy by the Smell of Anxiety. *PLoS ONE*, 4(6), e5987. <https://doi.org/10.1371/journal.pone.0005987>
- Radulescu, A. R., & Mujica-Parodi, L. R. (2013). Human Gender Differences in the Perception of Conspecific Alarm Chemosensory Cues. *PLoS ONE*, 8(7), e68485. <https://doi.org/10.1371/journal.pone.0068485>
- Rothkirch, M., & Hesselmann, G. (2018). No evidence for dorsal-stream-based priming under continuous flash suppression. *Consciousness and Cognition*, 64, 84–94. <https://doi.org/10.1016/j.concog.2018.05.011>
- Rubin, D., Botanov, Y., Hajcak, G., & Mujica-Parodi, L. R. (2012). Second-hand stress: Inhalation of stress sweat enhances neural response to neutral faces. *Social Cognitive and Affective Neuroscience*, 7(2), 208–212. <https://doi.org/10.1093/scan/nsq097>
- Sela, L., & Sobel, N. (2010). Human olfaction: A constant state of change-blindness. *Experimental Brain Research*, 205(1), 13–29. <https://doi.org/10.1007/s00221-010-2348-6>
- Silva, D. R., & Spielberger, C. D. (2007). Manual do Inventário de Estado-Traço de Ansiedade (STAI). *Mind Garden, Inc.*
- Soares, S. C., Lindström, B., Esteves, F., & Öhman, A. (2014). The Hidden Snake in the Grass: Superior Detection of Snakes in Challenging Attentional Conditions. *PLoS ONE*, 9, e114724. <https://doi.org/10.1371/journal.pone.0114724>
- Spielberger, C. D., Gorsuch, R. L., & Lushene, R. E. (1970). Manual for the state-trait anxiety inventory. *CA:Consulting Psychologists Press.*
- Susskind, J. M., Lee, D. H., Cusi, A., Feiman, R., Grabski, W., & Anderson, A. K. (2008). Expressing fear enhances sensory acquisition. *Nature Neuroscience*, 11(7), 843–850. <https://doi.org/10.1038/nn.2138>

Vuilleumier, P., Armony, J. L., Driver, J., & Dolan, R. J. (2003). Distinct spatial frequency sensitivities for processing faces and emotional expressions. *Nature Neuroscience*, *6*(6), 624–631. <https://doi.org/10.1038/nn1057>

World Medical Association. (2013). World Medical Association Declaration of Helsinki: Ethical principles for medical research involving human subjects. *JAMA*, *310*(20), 2191–2194. <https://doi.org/10.1001/jama.2013.281053>

Yamashiro, H., Yamamoto, H., Mano, H., Umeda, M., Higuchi, T., & Saiki, J. (2014). Activity in early visual areas predicts interindividual differences in binocular rivalry dynamics. *Journal of Neurophysiology*, *111*(6), 1190–1202. <https://doi.org/10.1152/jn.00509.2013>

Zeileis, A., & Grothendieck, G. (2005). zoo: S3 Infrastructure for Regular and Irregular Time Series. *Journal of Statistical Software*, *14*(1), 1–27. <https://doi.org/10.18637/jss.v014.i06>

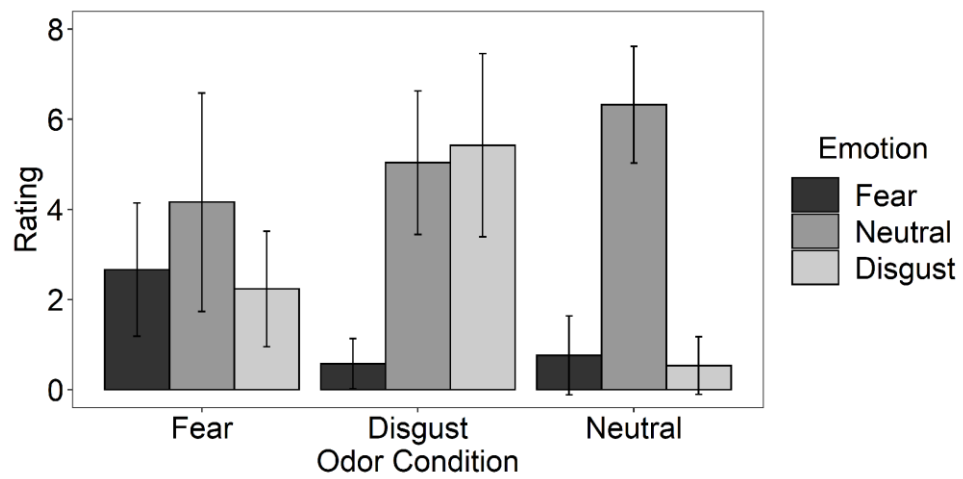
Zernecke, R., Haegler, K., Kleemann, A. M., Albrecht, J., Frank, T., Linn, J., Brückmann, H., & Wiesmann, M. (2011). Effects of Male Anxiety Chemosignals on the Evaluation of Happy Facial Expressions. *Journal of Psychophysiology*, *25*(3), 116–123. <https://doi.org/10.1027/0269-8803/a000047>

Zheng, Y., You, Y., Farias, A. R., Simon, J., Semin, G. R., Smeets, M. A., & Li, W. (2018). Human chemosignals of disgust facilitate food judgment. *Scientific Reports*, *8*(1), 17006. <https://doi.org/10.1038/s41598-018-35132-w>

Zhou, W., & Chen, D. (2009). Fear-Related Chemosignals Modulate Recognition of Fear in Ambiguous Facial Expressions. *Psychological Science*, *20*(2), 177–183. <https://doi.org/10.1111/j.1467-9280.2009.02263.x>

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Figure 4



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