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Emotional self-body odors do not influence the access to visual awareness by emotional faces

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A growing body of research suggests that emotional chemosignals in others' body odor (BO), particularly those sampled during fearful states, enhance emotional face perception in conscious and preconscious stages. For instance, emotional faces access visual awareness faster when presented with others' fear BOs. However, the effect of these emotional signals in self-BO, that is, one's own BO, is still neglected in the literature. In the present work, we sought to determine whether emotional self-BOs modify the access to visual awareness of emotional faces. Thirty-eight women underwent a breaking-Continuous Flash Suppression task in which they were asked to detect fearful, happy, and neutral faces, as quickly and accurately as possible, while being exposed to their fear, happiness, and neutral self-BOs. Self-BOs were previously collected and later delivered via an olfactometer, using an event-related design. Results showed a main effect of emotional faces, with happy faces being detected significantly faster than fearful and neutral faces. However, our hypothesis that fear self-BOs would lead to faster emotional face detection was not confirmed, as no effect of emotional self-BOs was found—this was confirmed with Bayesian analysis. Although caution is warranted when interpreting these results, our findings suggest that emotional face perception is not modulated by emotional self-BOs, contrasting with the literature on others' BOs. Further research is needed to understand the role of self-BOs in visual processing and emotion perception.

Key words: self-body odors, olfaction, emotion, face perception, visual awareness

Introduction

Humans use sensory information from themselves and others to navigate their social world. Particularly, there is growing evidence for a chemosensory communication in the case of emotional states (e.g. Pause 2017). Indeed, several studies have found that participants exposed to other people's BOs (receivers) collected under emotional contexts (emotional BOs) display behavioral and physiological responses that resemble the emotional state of the "donor," such as happiness (de Groot et al. 2015a), disgust (de Groot et al. 2012), anxiety (Rocha et al. 2018), aggression (Mutic et al. 2015), and fear (de Groot and Smeets 2017; Gomes et al. 2020). For instance, fear BOs trigger in the receiver a partial reproduction of the donors' fear state, characterized by an increased activation of the medial frontalis and corrugator supercilii facial muscles (de Groot et al. 2014b), part of the prototypical facial expression of fear (Ekman et al. 1972). The activation of these simulation processes affects not only a recipient's physiology but also their ability to scan the environment. Recently, Gomes and Semin (2021) showed that fear BOs elicit faster responses to threat-related events in a (nonsocial) foraging-vigilance task than neutral BOs (in the foraging-vigilance task, participants are given small monetary rewards for solving a central letter discrimination task (foraging simulation), while suffering strong monetary punishments for not detecting changes that occur in their peripheral visual field (threat simulation) (Gomes and Semin, 2021).

Of relevance to the present study, a growing body of research shows that emotional BOs can influence the perception of other ecologically relevant emotional stimuli, such as emotional faces (Calvi et al. 2020). For example, fear BOs seem to facilitate the recognition of fearful faces (Kamiloğlu et al. 2018) and to bias the perception of ambiguous faces as more fearful (Zhou and Chen 2009), suggesting a congruent effect between olfactory and visual emotional cues. But emotional BOs can also enhance emotional face perception on a more general level. For instance, fear-related BOs are associated

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with greater accuracy when recognizing happiness and anger in dynamic emotional faces (Rocha et al. 2018) and faster response time (RT) in general when classifying emotional faces (de Groot et al. 2015b).

Besides emotion recognition, there is evidence that emotional BOs enhance the conscious detection of emotional faces, as observed in two studies using a breaking-Continuous Flash Suppression (bCFS) paradigm (de Groot et al. 2018; Silva et al. 2020). The bCFS paradigm (Jiang et al. 2007) is a variant of the Continuous Flash Suppression technique (Tsuchiya and Koch 2005), a form of binocular rivalry which allows the presentation of a dominant pattern to one eye so that a low-contrast stimulus exhibited to the other eye is suppressed from visual awareness. In the bCFS task, the contrast of the stimulus is gradually increased until the stimulus is perceived consciously, thus "breaking" visual suppression. The time required by different stimuli to break suppression and to be consciously detected by the observer is considered a measure of access to visual awareness; shorter suppression duration of a stimulus type indicates a privileged access to visual consciousness (Gayet et al. 2014). De Groot et al. (2018) found that happiness BOs decreased the suppression duration of happy faces, whereas fear BOs decreased the suppression duration of fearful, happy, and neutral faces. Their findings suggest that, while happiness BOs facilitate the processing of congruent emotional information, fear BOs induce a state of generalized hypervigilance, which facilitates the processing of all social information. Later, Silva et al. (2020) showed that fear BOs lowered the suppression duration of fearful faces only, suggesting a fear-congruency effect. Despite the somehow inconsistent findings, both studies indicate that fear BOs from others enhance visual perception, perhaps allowing faster detection of (and response to) a stimulus in the environment, that is perceived as potentially dangerous, such as a fearful face. However, to the best of our knowledge, no studies have yet explored the role of fear BOs belonging to oneself (self-BOs) in the access to visual awareness by emotional faces.

Humans do not always have access to others' BOs, but they are constantly exposed to their own smell. Still, the literature on self-BOs is scarce and restricted to one sensory modality. For instance, Lundström et al. (2008) found that smelling the BO of strangers activates brain regions involved in emotion perception, while smelling the BO of a close friend or oneself does not activate those regions above a threshold. Pause et al. (1998) demonstrated a faster processing of self-BOs compared with strangers' BOs. Additionally, it has been shown that humans can identify their own BO (Platek et al. 2001), even in an implicit manner (Übel et al. 2017). Altogether, these findings seem to indicate that BOs are relevant not only for others but also for oneself. Yet, it remains unknown whether humans can also use emotional cues present in their own BO to modulate their visual perception of the social world, much like they do with emotional cues from others. This gap in the literature is surprising, given that our closest environment is our body, and we are constantly exposed to our own BO. In fact, the idea that emotional self-BOs can influence our interpretation of the world emerged from a proposal that started with Darwin (1872), positing that emotions serve first and foremost an egocentric adaptive function by inducing beneficial action for the organism.

In the present study, we aimed to explore, for the first time, whether emotional self-BOs modulate access to visual awareness of emotional faces, as previously found for others' emotional BOs (de Groot et al. 2018; Silva et al. 2020). To address this question, healthy women performed a bCFS task with fearful, happy, and neutral faces. At the same time, they were exposed to their fear, happiness, and neutral self-BOs—previously collected in the lab and presented through an olfactometer during the bCFS task. Given the lack of previous studies with emotional self-BOs, we outlined two distinct hypotheses based on the literature on others' emotional BOs.

> H1: If the effects of fear BOs on emotional face perception are restricted to congruent fearful faces (Silva et al. 2020), we expected that fear self-BOs would lead to a shorter suppression duration for fearful faces only.
>
> H2: In contrast, if fear BOs induce a hypervigilance state that enhances emotional face perception in general (de Groot et al. 2018), we expected that the suppression duration would be significantly shorter for all the faces during the exposure to fear self-BOs.

Material and methods

Participants

The final sample included 38 Caucasian women, students from the University of Aveiro, Portugal, aged between 18 and 35 years (*M* = 22.53, SD = 3.77). Only nonsmoker, heterosexual, right-handed, not-pregnant, and healthy (i.e. medication free, without any respiratory, metabolic, or mental illness) women were included. Additional inclusion criteria were reporting normal or corrected-to-normal vision; having Portuguese as a native language; and scoring in the normal range of the Portuguese version of the trait version of the State-trait Anxiety Inventory (STAI-T; Silva and Spielberger 2007), taking into account sex and age (present study: *M* = 33.61, SD = 5.14). Only women were included because, beyond outperforming men on most olfactory tasks (Brand and Millot 2001), women are more sensitive to fear-related BOs, regardless of the donors' sex (de Groot et al. 2014a), and are more accurate than men in identifying their BOs above chance (Platek et al. 2001). Olfactory function was measured using MONEX-40 (Freiherr et al. 2012). Participants who failed to identify 20 or more odors were excluded from the study and were given a 5€ voucher.

This experiment was part of a comprehensive study that included 4 sessions. In the first session, participants were informed of the general procedure of the study and that we aimed to investigate "the influence of odours in everyday life," while remaining were unaware of the emotional induction, sweat donation, and sweat exposure procedures. The next 3 sessions were separated by at least 1 week each, and included the collection of fear, happiness, and neutral self-BOs; the completion of an Affect Misattribution Task; and a bCFS task. The collection of self-BOs generated enough sweat samples to carry out the two experimental tasks. The findings from the Affect Misattribution Task will be presented elsewhere, as they are beyond the scope of this article.

All procedures were approved by the Ethics Committee of the University of Aveiro (ref. 9-2018) and conducted in accordance with the Declaration of Helsinki (World Medical Association 2013). Participants gave written informed consent before participation. At the end of their participation, they were fully debriefed about the purposes of the study and rewarded with a 65€ voucher.

Sweat donation procedure

All participants acted as BO donors and receivers and were tested individually. The three sweat samples (neutral, fear, and happiness) were collected on the same day: two in the morning and one in the afternoon, each separated by 2 h at least. Sweat donation always began with the neutral induction to avoid "emotional contamination," followed by the emotion inductions, counterbalanced between participants (e.g. ID1: neutral/fear/happiness; ID2: neutral/happiness/fear). See Supplementary Material for more information. For the fear and happiness induction, we used film-clips selected from a pilot study (see Supplementary Material), whereas neutral state was induced with a single 20-min video, previously used by members of our team (Ferreira et al. 2018). While watching the film-clips, participants wore two breastfeeding cotton pads, previously weighted and carefully placed by the experimenter under the participants' armpits. After each film-clip, participants indicated the intensity with which they had felt amusement, anger, anxiety, happiness, joy, surprise, sadness, fear, and disgust, using Likert scales ranging from 0 ("not at all") to 8 ("very much"). After each sweat donation, both cotton pads (left and right armpits) were weighted and cut into four quadrants. Lab temperature and humidity before and after sweat collection were measured to assess possible confounders.

For all sweat conditions, two samples were created, each with two quadrants of the left armpit and two quadrants of the right armpit, randomly chosen. The samples were then labeled and stored in a freezer at −20 °C.

Film-clips and Likert scales were presented on an ASUS VW227D LCD monitor (pixel resolution: 1920 × 1080; refresh rate: 60 Hz; display dimension: 26.5 × 47.5 cm) using the E-prime software (version 2.0) (Schneider et al. 2002).

Apparatus and stimuli

For the olfactory stimuli, one of the two samples of fear, happiness, and neutral self-BOs was removed from the freezer nearly 60 min prior to the experimental session.

The bCFS task was programmed in, and displayed with, Psychopy software (Peirce 2007). For the visual stimuli, 18 male faces depicting fearful, happy, and neutral expressions were retrieved from the Karolinska Directed Emotional Faces. Stimuli were presented as oval faces on a grayscale with equalized luminance, and were matched for low-level features and for low, medium, and high spatial frequency bands (for more information about stimuli selection and manipulation see Supplementary Material). Final stimuli contained the face at the center of one of the four quadrants, while a black fixation cross was shown in the middle (Fig. 1). As suppressors, we used high contrast, colorful, dynamic noise patches (Mondrian patterns), animated at 10 Hz.

Faces and suppressors were surrounded by a frame of black and white orthogonal lines, of equal thickness. This frame covered about 14° of visual angle, and faces were about 3.3° in both directions. To allow the presentation of different information to each eye (Engell and Quilliam 2020; Grave et al. 2021), participants wore red-blue anaglyph glasses; suppressors were always displayed to the dominant eye (red lens) and faces to the non-dominant eye (blue lens).

Procedures

After sweat collection, participants were again invited to the lab to perform the bCFS task. The time between the collection of the self-BOs and the bCFS task varied between 10 and 162 days ($M = 47$, SD = 45). This was due to circumstances not controllable by the experimenters, such as participants' availability, sickness, and use of medication. Participants were unaware that they would be exposed to their own sweat since this information could bias their performance. To prevent odor contamination, participants were instructed to refrain from using perfume, eating odorous food (e.g. garlic, spices, asparagus), and drinking alcohol or coffee between the evening before and the time of the experiment. If participants reported being sick or to have taken any medication, the session was postponed.

Before the bCFS task, eye dominance was assessed using the Miles test (Miles 1930). In this test, participants are instructed to extend both arms, create a triangular-shaped opening by putting together both hands and center this opening on a distant object on the wall (with both eyes). Next, they should alternatively close their right and left eye and indicate with which eye the object remains centered, that is, the dominant eye.

After determining eye dominance, participants completed the state version of the State-trait Anxiety Inventory (STAI-S) and were asked to indicate how angry, sad, happy, surprised, fearful, and disgusted they felt at the moment, using paper

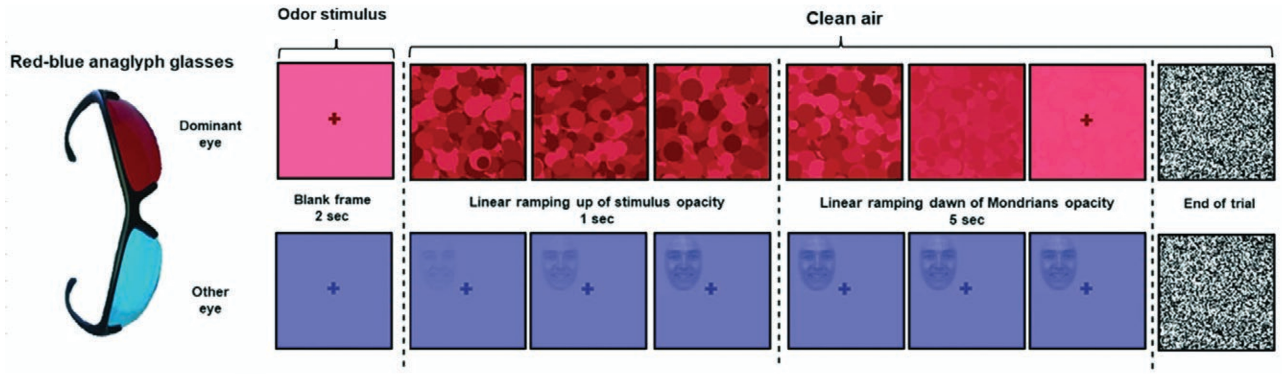

Fig. 1. Illustration of an example trial of the bCFS task.

Visual Analogue Scales (VASs; 10 cm) from 0 (“not at all”) to 10 (“very much”). Next, they were seated in front of a computer screen, their heads were stabilized by a chinrest, and the chair height was adjusted. Self-BOs were delivered through nasal tubes to each one of the participant’s nostrils and connected to a custom-built, four-channel, computer-controlled olfactometer (Lundström et al. 2010). Participants wore red-blue anaglyph glasses and were asked to always keep their gaze fixed on black fixation cross, presented at the center of the screen. Finally, they were instructed to indicate the position of a face stimulus (left, right) with respect to the fixation cross, as soon as they were able to detect a face (or any part of a face) and as accurately as possible, by pressing with their left or right index fingers either the “f” or “j” keys on a computer keyboard, respectively.

An event-related design was used, with each trial including one odor and one face stimulus. Each trial started with a blank frame with the black fixation cross (Fig. 1) displayed to both eyes for 2 s, simultaneously to odor presentation (fear, happiness, neutral). The face stimulus was then presented in one of the four quadrants of the frame (in random order), together with the Mondrian patterns covering the whole frame. During visual stimulation (or longer, in trials with response), only clean air was provided. The opacity of the face stimulus increased linearly from 0% to 60% over the course of 1 s, and then stayed at 60% until the participant’s response or until 6 s after stimulus onset (SO) in trials without response. On the other hand, the opacity of the Mondrian patterns stayed at 100% until 1 s, and then linearly decreased to 0% until the participant’s response or for a maximum of 6 s after SO. Immediately afterwards, a random white noise mask was presented, between 200 and 500 ms, in trials without response (in which face and Mondrians stayed for 6 s) or longer in trials with response (to guarantee the delivery of 6 s of clean air in all trials). The speed of access to visual awareness was analyzed via RT (in seconds), defined from the SO to the moment of a response button press.

The bCFS task was preceded by 32 practice trials, for which a separate set of face stimuli were used, while only clean air was delivered. The main task comprised 216 trials (6 actors × 3 faces × 3 self-BOs × 4 quadrants), with a mandatory break every 60 trials. Stimuli were presented in a semi-random order. After the bCFS task, participants completed a noCFS control task. The noCFS task was similar to the bCFS except that faces and suppressors were shown in red and blue colors to be picked up by both eyes, simultaneously. Each task lasted about 30 min.

Finally, participants were again asked to indicate how angry, sad, happy, surprised, fearful, and disgusted they felt at the moment, using paper VASs (10 cm) from 0 (“not at all”) to 10 (“very much”); and to rate how intense, familiar, and pleasant the self-BOs and the clean air were, using VASs from 0 (“nothing”) to 100 (“a lot”) on the computer screen. Odors were presented in random order and the rating task was programmed with E-prime (version 2.0; Schneider et al. 2002). The total session lasted about 65 min.

Statistical analysis

Significance levels were set at $\alpha = .05$. Repeated-measures ANOVA was computed to confirm if the emotion induction was successful, with 3 within-subject factors (condition: fear, happiness, neutral; emotional state: positive, negative (two scores were created based on participants’ self-report: one for negative emotions, containing the mean of fear and anxiety; and one for positive emotions, containing the mean of happiness, joy, and amusement); time: baseline, film-clip); to explore differences in perceived intensity, familiarity, and pleasantness of the odor stimuli after the completion of the tasks, with one within-subject factors (odor stimuli: fear self-BO, happiness self-BO, neutral self-BO, clean air); and to check for differences in lab conditions (i.e. temperature and humidity) and pads weight between sessions, each with two within-subject factors (session: fearful, happy, neutral; time: before after donation). Greenhouse–Geiser correction was performed in case of violation of sphericity, assessed via the Mauchly’s test. Post-hoc analyses with Bonferroni adjustment were computed. Analyses were performed using IBM-SPSS Statistics (IBM-SPSS Statistics for Windows, Version 28.0. IBM Corp).

For the bCFS and the noCFS analyses, only RTs of correct trials were considered (97.53% and 98.79%, respectively) and outliers were removed (1.15% and 1.44%, respectively, defined as RTs slower than M + 3 × SD, determined per individual, emotional self-BO, and emotional face). Analyses were performed with the *lmer* function of the *lmer4* package (Bates et al. 2015) in R (R Core Team 2020). A log transformation was considered due to the positive skewness of the data, observed through visual inspection. However, since results were similar using untransformed and log-transformed RT—and considering the arguments against RT transformation (Lo and Andrews 2015)—only untransformed RT is presented below.

Concerning the bCFS, our simpler model includes RT as a dependent variable, and self-BO × face as fixed effects. Different by-actor (to ensure that results were not driven by the specific actors for whom faces were selected) and by-subject slopes and intercepts were included as random effects. The following fixed effects were individually added as covariates to verify if they improved fit: age; STAI-T and STAI-S scores; self-reported anger, sadness, happiness, surprise, fear and disgust; odor intensity, familiarity, and pleasantness; lab temperature and humidity; samples’ weight; MONEX scores; and trial number (continuous variables were centered). Models containing age, STAI-T, and trial number were contrasted with the simpler model for fit using the *anova* function in the *car* package (Fox and Weisberg 2019), and the winning model was selected based on the *P* value provided by the *anova* function. The remaining models were not contrasted with the simpler model because of missing data; however, we confirmed whether each covariate influenced RT by testing each of these models individually. Models failing to converge were not considered as they would increase Type I error (Seedorff et al. 2019). Once the winning model was selected, we used the *anova* function of the *car* package (Fox and Weisberg 2019) to compute the Type-III tests with Satterthwaite approximation, and the *emmeans* package (Lenth 2020) to compute the post-hoc comparisons with Bonferroni adjustment (results remained the same using FDR, a less conservative correction) A Bayesian LMM was also fitted, to confirm null effects, using the *brms* package (Bürkner 2018).

Finally, the bCFS and the noCFS tasks were also compared using LMM (see SM). The simpler model comprised RT as a dependent variable, and task × face × self-BO as fixed effects. The procedures described above were followed to select and compute the winning model. Results are described in SM.

Results

Sweat donation

Results showed, as expected, significantly higher negative emotions ($P < 0.001$) and lower positive emotions after film-clips than baseline in fearful sessions ($P < 0.001$), and significantly higher positive emotions after film-clips than baseline in happy sessions ($P < 0.001$). No other significant differences between baseline and film-clips were found (all $P > 0.050$) (Fig. 2). Concerning baseline, positive and negative emotions did not significantly differ between sessions (all $P > 0.050$).

Regarding differences between sessions after film-clips, results showed significantly higher negative emotions in fearful than happy ($P < 0.001$) and neutral sessions ($P < 0.001$), and in neutral than happy sessions ($P = 0.012$) (Figure 3). Although we expected no significant differences between neutral and happy sessions, an average negative emotion of 0.42 in neutral sessions is still not indicative of a negative emotional state, as Likert scales ranged from 0 (“not at all”) to 8 (“very much”). Finally, film-clips in happy sessions were rated significantly more positive than fearful and neutral sessions, and film-clips in neutral sessions were rated significantly more positive than fearful sessions (all $P < 0.001$). This is consistent with our expectation that, compared to neutral film-clips, fearful and happy film-clips would lead to more negative and positive emotions, respectively, suggesting that emotion induction was successful.

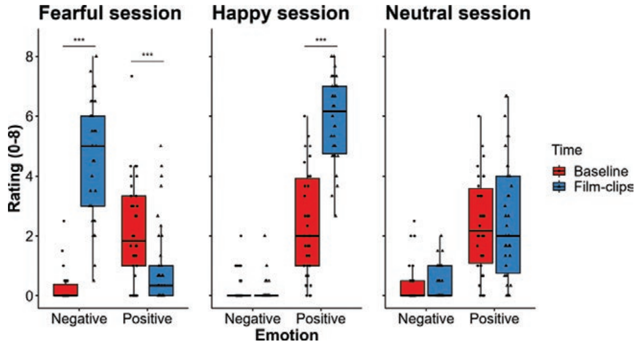

Fig. 2. Boxplot with jittered datapoints for subjective rating of negative (mean of the fear and anxiety) and positive emotions (mean of happiness, joy, and amusement) for each session after the visualization of baseline and film-clips. ***$P < .001$.

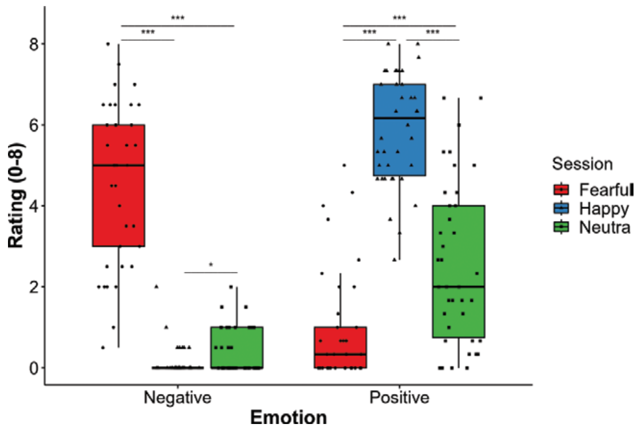

Fig. 3. Boxplot with jittered datapoints for subjective rating of negative (mean of the fear and anxiety) and positive emotions (mean of happiness, joy, and amusement) for each session after the visualization of film-clips. *** $P < .001$, * $P < .050$.

Concerning lab conditions, results showed a main effect of session in temperature, $F(1.28, 37.03) = 8.70$, $P = 0.003$, and humidity, $F(2,60) = 3.64$, $P = 0.032$. Particularly, post-hoc comparisons revealed that temperature was significantly lower in neutral than fearful ($P < 0.001$) and happy sessions ($P = 0.008$), and that humidity was significantly higher in happy than neutral sessions ($P = 0.023$) (see SM for more information).

Finally, we examined pads’ weight before and after sweat collection using delta, calculated as follows: the sum of the weight of left and right pads before sweat collection subtracted from the sum of the weight of left and right pads after sweat collection. Results showed a main effect of session, $F(1.52, 56.31) = 9.63$, $P < .001$, with significantly higher delta in fearful ($M = 0.08$, $SD = 0.11$) than happy sessions ($M = 0.03$, $SD = 0.03$, $P = 0.002$), and in neutral ($M = 0.06$, $SD = 0.07$) than happy sessions ($P = 0.009$).

bCFS task

The winning model included self-BO (fear, happiness, neutral) × face (fearful, happy, neutral) as fixed effects; trial number as covariate; and by-subject intercept and slope for face (1 + face|subject), and by-actor intercept (1|actor) as random factors. The remaining fixed effects did not significantly modulate RT. The winning model showed a marginal R^2 of 0.02, a conditional R^2 of 0.39, and an ICC of 0.38.

Type-III *F*-tests with Satterthwaite’s method revealed a main effect of face, $F(2, 38.1) = 13.26$, $P < 0.001$. Post-hoc analyses showed (Fig. 4) that happy faces ($M = 2.21$, $SE = 0.14$) were detected significantly faster than fearful faces ($M = 2.38$, $SE = 0.14$, $P < 0.001$) and neutral faces ($M = 2.36$, $SE = 0.14$, $P < 0.001$), with no significant difference between fearful and neutral faces ($P = 1.00$). There was also a main effect of trial number, $F(1, 7841.8) = 171.86$, $P < 0.001$, showing that RTs became faster over the course of the task. No main effect of self-BO, $F(2, 7795.8) = 0.47$, $P = 0.624$, and no significant self-BO × face interaction were observed, $F(4, 7795.6) = 0.68$, $P = 0.603$.

No self-BO effects were retrieved in the model. To verify whether this null result is robust, we conducted the same LMM using a full Bayesian method using the brms package (Bürkner 2018). We set a normal prior for population-level (fixed) effects with $M = 0$ and $SD = 5$, as well as a standard deviation of subject-specific (random) effects with a half student-*t* prior with 3 degrees of freedom, $M = 0$, and scaling parameter = 2.5. Results showed that neither happiness self-BOs ($\beta_{\text{mean}} = -0.02$, 95% Bayesian credible interval [−0.10, 0.07]) nor neutral self-BOs ($\beta_{\text{mean}} < 0$, 95% Bayesian credible interval [−0.07, 0.08]) had credible main effects on RT, nor did they interact with face (all $\beta_{\text{mean}} < 0.07$, all 95% Bayesian credible interval crossing zero). Next, we computed an identical Bayesian LMM without the predictor self-BO and compared the two models using a Bayesian leave-one-out cross validation based on the posterior likelihoods (Vehtari et al. 2017). Results showed that the model without self-BO had greater predictive ability (weight = 1) than the full model (weight = 0). It is thus possible to conclude that the emotional valence of the self-BO did not improve the ability to predict the RT in the bCFS task, supporting the conclusion that emotional self-BOs did not significantly affect RT in the frequentist LMM analyses.

Self-BO ratings

A main effect of odor was observed for familiarity ratings, $F(3, 102) = 3.25$, $P = 0.025$. Post-hoc comparisons revealed (Fig. 5) that participants rated fear self-BOs ($M = 35.34$, SE = 4.34) as significantly more familiar than clean air ($M = 27.30$, SE = 3.87, $P = 0.024$). A main effect for odor for intensity was also found, $F (3, 102) = 4.36$, $P = 0.006$, with participants rating fear ($M = 32.28$, SE = 4.67) and happiness self-BOs ($M = 28.30$, SE = 3.69) as significantly more intense than clean air ($M = 18.67$, SE = 3.46, both $P < .050$). No main effect of odor was observed for pleasantness (all $P > .050$) (due to a technical problem, data from 3 participants are missing [$N = 35$]).

Discussion

In this study, we aimed to investigate, for the first time, the effects of emotional self-BOs on emotional face perception by testing whether fear, happiness, and neutral self-BOs differently modulate the access to visual awareness of fearful, happy, and neutral faces.

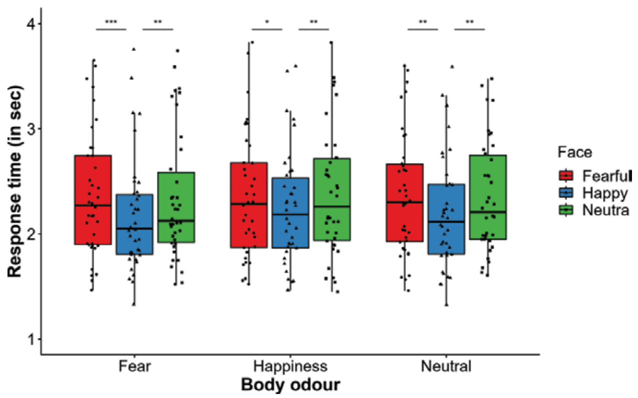

Fig. 4. Boxplot with jittered datapoints for RT (untransformed) to detect the location of a face stimulus in the bCFS task, as a function of the emotional valence of self-BO (fear, happiness, and neutral) and face (fearful, happy, and neutral). To facilitate visualization, significance levels were calculated from individual models for each self-BO. *** $P < .001$, ** $P < .010$, * $P < .050$.

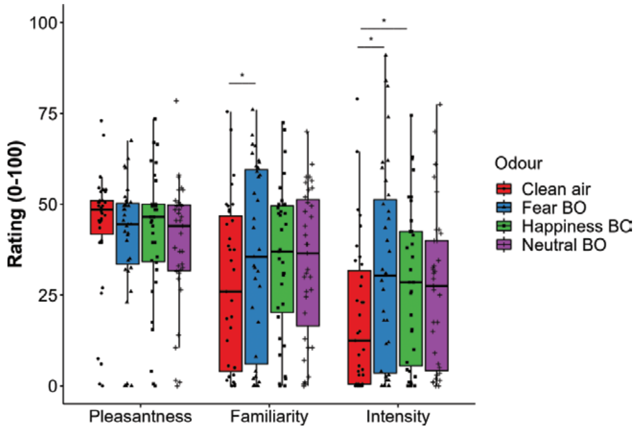

Fig. 5. Boxplots with jittered datapoints for pleasantness, familiarity, and intensity of odor stimuli (clean air, fear BO, happiness BO, and neutral BO). * $P < .050$.

Contrary to our hypotheses that fear self-BOs would facilitate the access to visual awareness of fearful faces or even all face stimuli (regardless of their facial expression), we did not find any significant interaction or main effodorect of the emotional content of self-BOs. Moreover, Bayesian statistics confirm this null finding, also showing that emotional self-BOs did not predict the access to visual awareness. One possible explanation for this null effect concerns the source of the BOs. In the current study, participants smelled their own BOs. In contrast to others' BOs, self-BOs are familiar olfactory stimulus to which individuals are always exposed to, regardless of their emotional content. Moreover, it is possible that self-BOs are of foremost importance for self-recognition mechanisms and, therefore, are perceived as safety signals, independently of their emotional content. For instance, Platek et al. (2004) found that smelling (non-emotional) self-BOs facilitates the recognition of one's own face, compared to no odor, androsterone, phenylethanol, and BOs from other women and men. Hence, even though there are no studies directly comparing the perception of emotional BOs belonging to others versus to oneself, we suggest that the emotional cues presented in BOs have distinct roles depending on their receivers: while emotional BOs belonging to others may be used to unconsciously perceive the emotional state of others and to facilitate the perception of (and response to) socioemotional events and the surroundings, emotional BOs belonging to oneself may trigger self-recognition mechanisms, regardless of their emotional content.

Similar to other sensory systems, olfaction is a specialized visceral system that projects to the insular cortex (Berntson et al. 2019) and is relevant for the sense of self (Strigo and Craig 2016). A study by Perl et al. (2020) revealed that humans bring their hands to their faces (close to the nose) several times, which increases the sniffing volume. Even though this behavior intensifies after a handshake, the act of sniffing their own hands is still frequent (e.g. 22% of the time; Frumin et al. 2015). Hence, the authors postulated that sniffing their own hands is a way to unconsciously obtain information about others, through their BOs, but also about themselves. Perl et al. also argued that smelling oneself can be compared to looking in the mirror, as both behaviors serve to reassure a sense of self and to reduce stress and anxiety (Perl et al. 2020). From this perspective, self-BOs can be used to regulate one's internal environment, rather than to modulate the perception of the social world, as is the case for others' BOs. Although there are no studies with emotional self-BOs, previous studies using non-emotional self-BOs seem to support this theory. Lundstrom et al. (2008) showed that smelling a stranger's BO activates brain regions involved in the processing of threatening stimuli, while smelling self-BO or the BO of a close friend does not activate those regions above the threshold. There is also evidence that, despite humans with high levels of disgust proneness not being able to correctly identify their own BO, self-BO are rated as more positive and less disgusting than strangers' BOs (Übel et al. 2017), even when only a scenario is imagined where the source of BO is external or internal (Liuzza et al. 2017). Furthermore, Übel et al. (2017) suggested that self-BOs do not induce disgust because the possibility of becoming infected when exposed to their own BO is non-existent. This analogy can be extended to fear self-BOs, insofar as, unless there is some psychopathology associated, it makes sense that we do not process the signals from our body as threatening to ourselves. These observations corroborate the idea that recognition mechanisms can play a role here, suggesting that humans do not process their own BO as a stimulus that conveys threat. This evidence can help to explain the null effect of fear self-BOs in visual perception in the present study.

Besides the source of BOs, it is important to contemplate a few methodological aspects when interpreting the results. Concerning the odor presentation, in the two studies that most closely resemble the present one—in which bCFS paradigms were used to explore the effects of others' emotional BOs—each odor stimulus was continuously presented in separated blocks, with no pause between trials (de Groot et al. 2018; Silva et al. 2020). For instance, de Groot et al. (2018) used an exposure time of approximately 4 min per block, and a 5-min washout period between blocks. In contrast, we used an event-related design to minimize a potential habituation effect, which could have been critical due to the use of self-BOs; since humans are constantly exposed to their own BO, they might be more prone to habituation or desensitization when exposed to those stimuli on an experimental setting. Particularly, each trial included one self-BO and one face stimulus, with self-BOs being presented for 2 s before visual stimulus display and clean air being provided during visual presentation. As such, it could be the case that emotional BOs (regardless of whether they belong to oneself or to others) only modulate the access to visual awareness when they are presented for longer durations, rather than shorter exposure durations with rapid fluctuations between emotions on a trial-by-trial basis, an effect that has yet to be explored. Nevertheless, there are other studies in which others' BOs are presented for shorter durations, showing the engagement of brain areas involved in the processing of social and emotional stimuli (Zheng et al. 2018). There is also evidence that odors can induce behavioral responses within approximately 1 s after sniff onset (see Olofsson 2014). Taking this into account, we suggest that an exposure of 2 s may be sufficient for the emotional self-BOs to be detected and influence visual perception if there was indeed an effect of the emotional content of the odor stimulus. Still, given the lack of studies using a similar design, our results should be interpreted with caution and future studies should be conducted with emotional BOs and faces alternating on a trial-by-trial basis.

Another methodological aspect to consider is odor delivery, with BOs being placed in jars (de Groot et al. 2018; Silva et al. 2020) versus in a 4-channel olfactometer connected to the participants' nostril. The olfactometer allowed us to define a specific and precise exposure time and onset–offset release (Lundström et al. 2010). Since the nasal tubing was directly inserted into participants' nostrils, we were able to guarantee that participants were being exposed to the stimulus (unless they did not inhale, which cannot be fully excluded) for a specific amount of time (2 s).

Another possible explanation for the null effect concerns an insufficient or ineffective sweat collection. Arguing against this, we found that participants rated fear and happiness self-BOs as more familiar and intense than clean air, with no significant differences between happiness, fear, and neutral self-BOs. This indicates that self-BOs contain some type of distinctive features in comparison to clean air, which suggests that the sweat collection was successful. Similarly, we found that pads were significantly heavier after than before emotional induction and that there were significant differences in pads' weight between emotional conditions. For instance, fear self-BOs weighed significantly more than happiness self-BOs, which can be explained by the arousal (and thus increased respiration) induced by the fearful film-clips. Somehow surprising, however, neutral self-BOs weighed significantly more than those of happiness, which may be due to the order of conditions: neutral self-BOs were always collected first to exclude any effects from previous emotional conditions, but the fact that the participants were performing the task for the first time, may have increased their activation levels. Despite our results showing differences between lab conditions, there is no evidence that temperature and humidity can affect the quantity and quality of sweat production with such low variations. The difference between all conditions was less than 1 °C and 1% for temperature and humidity (see Supplementary Material). Finally, even though the donor and receiver of the BOs were the same person, the time of providing and sensing the odor was not. Although it seems that odor freezing does significantly affect perceived hedonicity (Lenochova et al. 2008), we cannot fully exclude that, in the present study, the effect of familiarity during the judgement of self-BOs and clean air was due to the time between odor collection and exposure. Nevertheless, it is well established in the literature that humans produce stable body odor signatures and are able to recognize and identify themselves and others through olfaction (e.g. self-recognition; Porter 1998). Still, we recommend that future studies decrease (or at least control) the time between odor collection and exposure.

Finally, although the literature strongly suggests that smelling an emotional BO from a stranger facilitates emotional face perception (see Damon et al. 2021), we cannot dismiss the existence of null findings that have emerged in other studies and align with the present study, but were not reported. Indeed, the chemosensory field is not an exception when it comes to publication bias, in that "positive" findings are reported more often and rapidly than non-significant ones (see Damon et al. 2021). Along these lines, there is evidence that valeric acid (a sweat-like compound) does not affect the recognition of neutral, happy, and disgusted dynamic faces (Syrjänen et al. 2017). Although this study is not comparable to the current study as no human sweat was used, it highlights mixed findings in the field. Therefore, we recommend that further efforts in this line of research should follow Open Science practices and publish statistically significant findings, as well as lack thereof. An Open Science approach would be particularly helpful to investigate the boundaries of influence of self-BOs.

Concerning the main effect of emotional faces, we found that the suppression duration for happy faces was significantly shorter than for fearful and neutral faces, regardless of the odor valence. Despite conflicting with previous studies showing privileged access to visual awareness by fearful faces—as reviewed by Hedger et al. (2016), our findings are congruent with evidence of faster detection of happy faces in bCFS tasks (Korb et al., 2017; de Groot et al. 2018; Grave et al. 2021), thus suggesting a privileged preconscious processing of those stimuli. This happy advantage is also observed in other paradigms, see Pool et al. (2016) for a review. Some authors argue that this effect is related to the emotional content of the stimuli (Becker et al. 2011; Wirth and Wentura

2020), as happy faces convey relevant and positive social cues (e.g. enjoyment, affiliation) linked to reward and attachment (Rychlowska et al. 2017). However, a happy advantage may also be explained by the low-level visual properties of the stimuli (Nummenmaa and Calvo 2015). For instance, teeth exposure could increase the contrast in the region around the mouth which, in turn, could contribute to a more rapid and accurate detection (Calvo and Nummenmaa 2008) and recognition of happy faces (Calvo and Nummenmaa 2016). In our study, face stimuli were carefully selected (e.g. the presence of teeth in both happy and fearful conditions) and prepared to avoid variations in size, orientation, color, and contrast, thus minimizing the potential role of low-level features. Moreover, no significant differences between emotion conditions were observed in low, medium, and high spatial frequencies. Still, future studies would benefit from including a control condition that modulates the emotional content while keeping the low-level properties constant, such as using an inverted and a scramble faces.

Although our study showed that emotional self-BOs do not influence the access to visual awareness by emotional faces, further studies need to confirm this effect. Being this the first exploratory study to assess the influence of self-BOs on emotional face perception, there is still a long way to explore in this field. Even more, future studies with different paradigms should be implemented. One methodological option, which could be considered a limitation in the current study, is the inclusion of an odor control condition. Indeed, we did not include an odor control condition as it would have increased the number of required sweat samples beyond our available resources and render the procedure exhausting for participants. Another important point that should be considered is the use of questionnaires to evaluate the interoceptive and emotional regulation skills of the participants, helping to understand whether self-BOs were processed as non-dangerous and a safe cue, as occurs with other interoceptive sensory information arising from our own body (Tsakiris and De Preester 2018). Finally, following the idea that self-BOs may trigger self-recognition mechanisms (e.g. self-face; Platek et al. 2004), it would be interesting to investigate whether emotional cues presented in one's BOs modulate their ability to detect or recognize their own emotional facial expressions.

Conclusion

In summary, the access to visual awareness by emotional faces does not seem to be driven by the emotional content of self-BOs. However, more research is needed to explore the effects of self-BOs, not only in visual perception but also in self-recognition mechanisms.

Supplementary Data

Supplementary material can be found at http://www.chemse.oxfordjournals.org/

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Marta Rocha (Conceptualization, Methodology, Software, Formal analysis, Investigation, Data Curation, Resources, Writing—Original Draft), Joana Grave (Formal analysis, Data Curation, Software, Writing—Review & Editing), Sebastian Korb (Conceptualization, Methodology, Software, Data Curation, Writing—Review & Editing), Valentina Parma (Conceptualization, Methodology, Writing—Review & Editing), Gün R. Semin (Conceptualization, Methodology, Resources, Writing—Review & Editing, Funding acquisition), and ssSandra Cristina Soares (Conceptualization, Methodology, Resources, Writing—Review & Editing, Supervision)

Conflict of interest

None declared.

Data Availability

The data and code underlying this article are available in the Open Science Framework, at https://osf.io/d3aev/.

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