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Research paper

# Sniffing out a solution: How emotional body odors can improve mindfulness therapy for social anxiety

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ABSTRACT

*Background:* Human body odors (BOs) serve as an effective means of social communication, with individuals exposed to emotional BOs experiencing a partial replication of the sender's affective state. This phenomenon may be particularly relevant in conditions where social interactions are impaired, such as social anxiety. Our study aimed to investigate if emotional human BOs could augment the benefits of mindfulness-based interventions.
*Methods:* We enrolled 48 women with social anxiety symptoms and assigned them to groups exposed to happiness BO, fear BO, or clean air. Participants engaged in mindfulness practice over two consecutive days, which included breathing, meditation, and relaxation exercises. During these interventions, the odor specific to each group was presented. Affective symptoms were assessed at the beginning and end of each day, with heart rate variability (HRV) and skin conductance level (SCL) recorded during the intervention.
*Results:* Self-reported anxiety level revealed a significant reduction in anxiety on the second day for both happiness and fear conditions, but not for the clean air group. However, on a physiological level, fear BO exposure compared to clean air led to decreased HRV, indicating that fear BO may induce a less physiological relaxed state. No significant differences were observed in SCL between odor conditions.
*Conclusions:* These findings suggest that exposure to BOs triggers the perception of a "social presence", improving the ecological validity of a psychological treatment. If replicated and expanded, these findings could pave the way for using BOs as catalysts in existing therapies.

## 1. Introduction

Body odors (BOs) carry chemical signals that convey social information from individuals in our surroundings (Calvi et al., 2020; Dal Bò et al., 2020; Parma et al., 2017). It has also been shown that chemicals in BOs produced by individuals in specific emotional states can induce an "emotional contagion" in receivers (i.e., a partial reproduction of the sender's affective state). This phenomenon has been demonstrated for both positive and negative emotions, including happiness, fear, anxiety, aggression, and disgust (Calvi et al., 2020). Accumulating evidence indicates that the transmission of fear through BOs can significantly influence receivers. Research has demonstrated that fear BO can induce a state of vigilance (Chen et al., 2006), modulate perception of facial expressions (Zhou and Chen, 2009), and impact accuracy in visual search tasks (de Groot et al., 2012). Moreover, exposure to negative emotional BOs, such as fear or anxiety BO is associated with a reduction in cardiac parasympathetic activity, as indicated by a decreasing heart rate variability (HRV; Ferreira et al., 2018; Rocha et al., 2018). Recent meta-

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analyses have further confirmed the statistical robustness of these effects (de Groot and Smeets, 2017). Similarly, there is a growing body of evidence suggesting that positive emotions can also be transmitted through BOs. For instance, studies have shown that happiness BO can induce facial expressions of happiness (de Groot et al., 2015a) and lead to increased creativity and reduced heart rate in receivers (Ortegón et al., 2022, 2023). However, while these effects have been well-documented in healthy individuals, the potential effects of BOs on the affective states of individuals with psychological disorders remain largely speculative.

Social anxiety is characterized by the fear of social situations in which the individual can be evaluated or judged negatively by others, leading to avoidance of those situations or facing them with intense anxiety and fear (American Psychiatric Association and Association, 2013). Despite individuals with social anxiety being characterized by increased emotional reactions toward social stimuli (e.g., Goldin et al., 2009), from a physiological point of view, the picture is more composite. The most common measures used to investigate psychological reactivity are the HRV and the skin conductance level (SCL), which provide complementary information about the autonomic nervous system (ANS). HRV is essential for studying the parasympathetic branch of the ANS because it reflects vagus nerve activity and serves as a measure of overall well-being and health (Task Force, 1996; Thayer and Lane, 2000). Low HRV indicates impaired vagal function and difficulties in emotion regulation and stress reactivity (Hansen et al., 2003; Mather and Thayer, 2018; Siennicka et al., 2019). On the other side, SCL measures sympathetic nervous system arousal indicating immediate physiological responses to stress or emotional stimuli via sympathetic activation (Boucsein, 2012). Together, they help in understanding how individuals respond to and recover from stress. In individuals with social anxiety, studies have consistently shown a reduction of HRV compared to controls (Alvares et al., 2013; Cheng et al., 2022), indicating reduced parasympathetic activation. However, despite the perceived increased physiological arousal, these individuals often exhibit a similar SCL (Constantinou et al., 2021; Edelmann and Baker, 2002; Miers et al., 2011), demonstrating that increased subjective distress does not always correspond with heightened physiological reactivity (Lang and McTeague, 2009).

Cognitive Behavioural Therapy (CBT) in combination with pharmacotherapy is generally used as a first-line treatment (Bandelow et al., 2017). However, whilst being an effective psychotherapy (Stewart and Chambless, 2009), a considerable portion of individuals receiving CBT do not achieve clinically significant improvements (Rodebaugh et al., 2004). This has led to the rise of alternative treatments, such as mindfulness-based therapy (Hofmann and Gómez, 2017). A common element within mindfulness interventions pertains to fostering non-judgmental self-focused attention on present sensations, thoughts, and emotions (Marlatt and Kristeller, 1999), which can be used to counteract the cognitive biases that typify the disorder (Gibb et al., 2022). Even brief mindfulness-based interventions with a duration of about 10–25 min have been shown to reduce symptoms of social anxiety and stress (Cassin and Rector, 2011; Mohan et al., 2011), improve overall mental and physical well-being (Zeidan et al., 2010), and affect cardiovascular variables (heart rate and blood pressure; Zeidan et al., 2010). However, despite the availability of alternative psychotherapies, a substantial number of patients remain symptomatic (Cuijpers et al., 2021; Loerinc et al., 2015). Moreover, rates of anxiety have increased during the COVID-19 pandemic, especially among females and in younger age groups (Santomauro et al., 2021), further highlighting a need for equipping our mental health systems and enhancing currently available treatments.

In the present work, for the first time, we aimed to test whether the addition of happiness BO as a contextual stimulus, through the emotional contagion phenomenon, could modulate the benefits of a brief mindfulness training in terms of leading to a greater decrease in anxiety symptoms and improvement in mood, in comparison to mindfulness performed with clean air. We also introduced the fear BO condition to examine the specificity of the happiness BO effect and to compare it to a negative, and thus opposite, emotion. Moreover, in order to investigate the ANS responses to the association between emotional BOs and mindfulness training, participants' HRV and SCL were measured throughout the intervention. Specifically, we hypothesized that the group exposed to happiness BO would report decreased anxiety state level and improvement of mood at the end of the mindfulness intervention, a higher HRV, reflecting overall well-being and health (Task Force, 1996; Thayer and Lane, 2000), and lower SCL, reflecting lower activity of the sympathetic nervous system (Boucsein, 2012), compared to the groups exposed to fear BO and clean air. Furthermore, we expected that the group exposed to fear BO would report a higher anxiety state level at the end of the mindfulness intervention, a lower HRV, and higher SCL compared to the group exposed to clean air. Since a previous study (Mahmut et al., 2023) has shown that the exposure to an ambient odor (e.g., lavender) during sessions of progressive muscle relaxation training does not improve the behavioural and physiological effects of the relaxation, we expected the foreseen results to be related to the intrinsic social information transmitted by the BOs and not to the perceptual differences between the three conditions.

The study was structured around two brief mindfulness sessions conducted over consecutive days. On the second day, a stress-inducing task preceded the second mindfulness session. This design enabled us to explore two main objectives: 1) assessing the impact of emotional BOs on a single mindfulness session, analyzed on the first day; and 2) examining the effects of emotional body odors on an additional mindfulness session, in a condition of elevated levels of perceived anxiety.

## 2. Methods

### 2.1. Design

The present single-centre study was conducted at the University of Padua, Italy, as a part of the European Project *Potion*. The behavioural data hypotheses and analyses were preregistered at the ISRCTN Registry (No. 64408867). Due to the novelty and exploratory nature of the present study, we did not perform an a priori power analysis. The preregistration included an additional group composed of individuals with depressive symptoms. Due to technical issues, it was not possible to collect enough data for this group. See Supplementary material for further information about this additional group. The study employed a single-blind, between-subjects quasi-randomized design, where participants with social anxiety underwent two sessions of mindfulness meditation while randomized to 1 of 3 odor conditions: Mindfulness while exposed to BO collected from a happiness-inducing situation (happiness BO), mindfulness while exposed to BO collected from a fear-inducing situation (fear BO), or mindfulness while exposed to clean air (control condition).

### 2.2. Body odor collection and preparation

Sweat samples collected as a distinct part of the project at the Instituto Superior de Psicologia Aplicada (Lisbon, Portugal) have been used. The collection of the sweat samples was carried out before the experimental sessions from a different group of participants, called "body odor donors". The emotional induction was performed by means of fear-inducing or happiness-inducing video clips (25 min duration) while the sweat was collected by placing sterilized cotton pads attached to the armpit. The effectiveness of this procedure has already been reported in previous studies (De Groot et al., 2014b; de Groot et al., 2014a; de Groot et al., 2015a). Details about the body odor collection are reported in the Supplementary Material. The analyses of the reported emotional states of body odor donors confirmed that the emotional induction procedure was successful (see Supplementary results). After the emotional induction, pads were removed, frozen at −80 °C, shipped to the University of Padova (Italy) in dry ice and stored again at −80 °C. The reliability of this delivery method has been confirmed by a previous study (Gomes et al., 2020).

Pads were prepared to reduce the effects of gender and individual variability (Mitro et al., 2012; Parma et al., 2017). While frozen, each pad was cut into 8 equal pieces. Then, following a randomization script, a super-donor was created by selecting four pieces from the same emotional condition: one from the left armpit of a male donor, one from the right armpit of another male, one from the left armpit of a female donor, and one from the right armpit of another female. Super-donors were placed in a new glass jar and stored again at −80 °C until one hour before the experimental session.

The three odor conditions (happiness BO, fear BO, and clean air) were rated by another group of participants (recruited for a related study; Dal Bò et al., 2024) by means of intensity, pleasantness and familiarity on a 100-point Likert scale. Participants did not rate the three odor conditions as different in terms of pleasantness [all $\beta < 4.04$, $t < 1.82$, $p > .07$], familiarity [all $\beta < 2.10$, $t < 0.94$, $p > .35$] and intensity [all $\beta < 0.37$, $t < 0.18$, $p > .74$]. These results confirmed that the three odor conditions were not consciously perceived as different. See Table 1 for mean and standard deviations of odor ratings.

### 2.3. Participants assessment

Through a survey conducted on the online platform Qualtrics, subjects were screened for the following inclusion criteria: 1) Aged 18–35; 2) Female gender; 3) Non-smoker; 4) Scoring ≥50 on the Liebowitz Social Anxiety Scale in its self-report formulation (LSAS-SR; Liebowitz, 2003). The LSAS is a 24-item questionnaire rating on a 4-point scale the fear and avoidance experienced in a range of social and performance situations. Scores range from 0 to 144 and, according to the manual, a score of 50 or 60 or above is highly predictive of a diagnosis of social anxiety (Liebowitz, 2003) with generalised characteristics (i.e., with social anxiety and avoidance in several social conditions). While two papers suggest 60 as the best score to optimize accuracy (Mennin et al., 2002; Rytwinski et al., 2009) others consider 50 a better cut-off suggesting also cultural and national variations (Santos et al., 2015; Soykan et al., 2003). We decided to go for the cut-off of 50 to increase sensitivity and reduce the number of subjects with social anxiety not recognized at the screening. Due to the subsequent clinical evaluation, we were able to exclude potential false positives at the LSAS screening. Subjects were excluded if they reported: 1) Presence of chronic rhinitis or any other condition that could affect the ability to perceive odors; 2) Pregnancy or breastfeeding; 3) Other mental disorders (other than Social Anxiety Disorder), including substance abuse disorders, severe somatic or neurological conditions; 4) Use of psychotropic drugs at the moment of the recruitment (including antidepressants, antipsychotics, anxiolytics and mood stabilizers); 5) Incapability to understand and to give informed consent. In this study, only women were included, as previous research has demonstrated that gender influences the processing of human body odor (Dal Bò et al., 2021; Krajnik et al., 2014; Martins et al., 2005). Additionally, women have shown a stronger inclination toward social-emotional stimuli compared to men (Lübke et al., 2012; Proverbio et al., 2008). By deliberately selecting a homogeneous female sample, potential gender-related biases were minimized, thereby strengthening the study's analytical power.

Subjects fulfilling the screening criteria were invited for a clinical interview, during which social anxiety symptoms were confirmed by the module F of the Structured Clinical Interview for DSM-5 (SCID-5-CV; First et al., 2016, 2017). Moreover, participants were tested for the presence of anosmia or hyposmia with the Sniffin' Sticks test, a standardized test commonly used to assess olfactory abilities (Burghart Instruments, Wedel, Germany; Hummel et al., 1997; see Supplementary material for a description of the test). Participants were compensated €13 for their participation. The present study was conducted with the adequate understanding and written informed consent in accordance with the Declaration of Helsinki and was approved by the local Ethics Committee, University of Padua (prot. no. 3667).

**Table 1**
Mean and standard deviation of odor ratings.

| Odor | Pleasantness | Intensity | Familiarity |
|---|---|---|---|
| Clean air | 38.94 (22.33) | 16.15 (18.46) | 23.60 (21.15) |
| Happiness BO | 41.37 (21.45) | 15.21 (18.27) | 25.37 (22.21) |
| Fear BO | 39.33 (20.73) | 15.67 (17.32) | 25.48 (22.84) |

*Notes.* Data are reported M (SD).

### 2.4. Treatment procedure

After providing informed consent, participants were randomly assigned to one of the three odor conditions (fear BO, happiness BO, clean air). The quasi-randomization was conducted in order that two consecutive participants were tested on the same day with the same odor, as each sweat pad was used twice. This procedure was applied to maximize the pads and to not switch the olfactometer on the same day. The study was composed of two experimental sessions performed on two consecutive days. Before each experimental session, participants were told to refrain from eating and drinking anything except water one hour before the appointment. Individuals performed the two mindfulness sessions with the same odor condition.

On the first day, at the beginning of the session, participants' anxiety level was assessed using the State-Trait Anxiety Inventory, state version (STAI-Y1; Spielberger et al., 1983). Mood symptoms were assessed by the Profile of Mood States, short form (POMS-SF; Curran et al., 1995). Moreover, participants' levels of present-moment attention and awareness were measured with the State Mindfulness Scale (SMS; Ruimi et al., 2022). For details about questionnaires see Supplementary materials.

Subsequently, the sensors for the recording of the heart rate and skin conductance were positioned and a three-minute rest baseline was recorded. At this point, headphones and a nasal cannula were positioned, and the mindfulness training began. The physiological signals (i.e., heart rate and skin conductance) were continuously recorded throughout the intervention. After the mindfulness training, participants completed the STAI-Y1 and POMS-SF questionnaires once again.

On the second day, after completing the STAI-Y1 and POMS-SF questionnaires and the three-minute resting-state recording of their heart rate and skin conductance, a stress induction procedure was implemented to evoke a social stress response. Specifically, participants were told that they would have to make a short presentation at the end of the study session on a predetermined topic in front of a small audience. Since in individuals with social anxiety the anxiety level mainly increases in response to social situations, we introduced a social stress induction to increase participants' anxiety level before the mindfulness treatment to enhance its effectiveness. This procedure was introduced only on the second day of intervention to prevent dropouts. The STAI-Y1 questionnaire was administered again after the stress induction to assess the effectiveness of the procedure. Then, as the day before, the participants performed the mindfulness training while the same odor of Day 1 was presented, and their heart rate and skin conductance were recorded. After the training, the STAI-Y1 questionnaire was administered again. Finally, they were told they no longer had to make a presentation. In Fig. 1 an overview of the study design is presented. Fear BO, happiness BO, and clean air were delivered with a custom-built, continuous airflow, computer-controlled olfactometer with 3 lines: one providing baseline odorless air and the other two connected to the airtight jars containing the super-donor pads (fear and happiness). The olfactometer was specifically built for the European Project Potion. Airflow was kept constant between 50 and 70 ml/min. Odorous or odorless air was delivered directly to both nostrils with a nasal cannula during the mindfulness training. The mindfulness training was performed using two mindfulness practices presented through recorded audio tracks

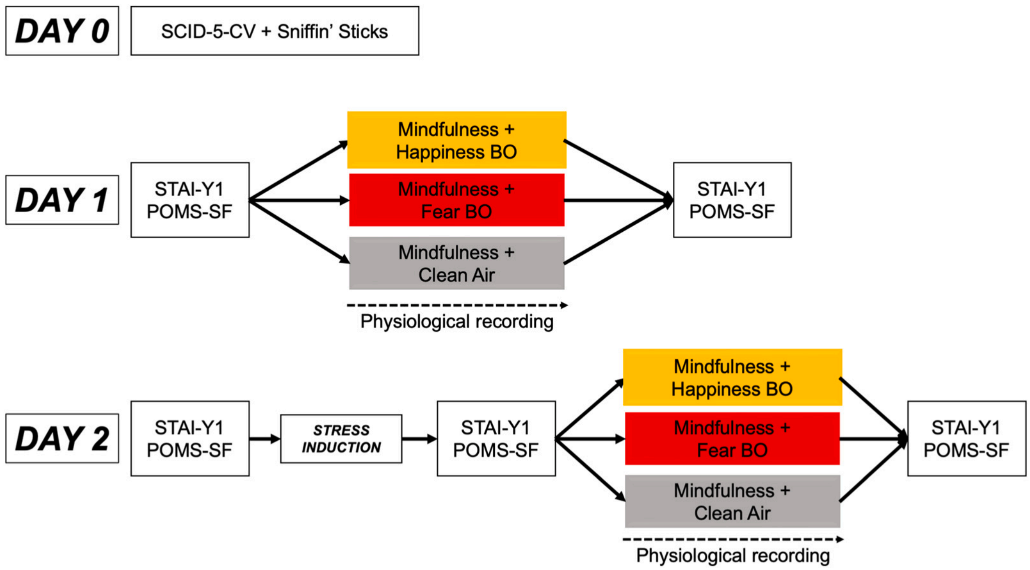


**Fig. 1.** Overview of the study design.

available from a smartphone app called “Con tatto” (developer LifeSTech research team). The two practices (“The breath that frees”, which was 9 min long, and “The thin breath”, which was 15 min long) comprised breathing, meditation and relaxation exercises, with a focus on bodily sensations elicited by the practices. The participant's task was to follow the guiding voice, be present in the moment, and feel their bodily sensation and their breathing. The total length of the session was about 24 min.

### *2.5. Physiological data acquisition and analysis*

Physiological measures were recorded with a sampling rate of 500 Hz by means of a wearable device (Shimmer3 GSR+ Unit, Shimmer 2018, Realtime Technologies Ltd., Dublin, Ireland). The photoplethysmograph (PPG) signal was recorded from the left ring finger to obtain the heart rate (HR). Specifically, the blood volume changes are detected by means of an optical pulse sensor and, since the electrical and the mechanical activities of the heart are coupled, this allows the determination of the inter-beat intervals. Then, the signal was analyzed offline using Kubios HRV Analysis Software 3.3.1 (Matlab, Kuopio, Finland), which allows the extraction of the time- and frequency-domain HRV parameters. Skin conductance (SC) was recorded using two 8 mm snap-style finger Ag/AgCl electrodes placed on the left hand's distal phalanges of the index and middle fingers. Details on the preprocessing and analysis of the physiological data are reported in the Supplementary material.

Finally, to investigate HRV and SCL modifications during the mindfulness training, the HRV and the SCL values measured during the baseline period have been subtracted from the values obtained during the eight 3-min time windows obtained during the mindfulness. However, on day 2, because the stress induction occurred after the 3-min baseline, the baseline correction was computed by subtracting the HRV and SCL values obtained in the first 3-min time window, from the values obtained during the remaining seven 3-min time windows. To analyze the pattern of HRV and SCL modification during the mindfulness in the three odor groups, to reduce the number of comparisons, only four time points were selected for the statistical analysis (3–6 min, 9–12 min, 15–18 min, 21–24 min).

### *2.6. Statistical analysis*

The Kolmogorov–Smirnov test was utilized to assess the normality of the distribution. Significant main effects ($p < .05$) were followed by Tukey HSD post-hoc tests to correct for multiple comparisons. First, three separate analyses of variance (ANOVAs) with Odor condition (happiness BO, fear BO, clean air) as a between-subject factor were conducted on age, education, SMS score, and LSAS score. Then, for day 1, a mixed ANOVA with Odor condition as a between-subject factor and Time (start, end of the training session) as a within-subject factor was conducted on the STAI-Y1 score. For day 2, a mixed ANOVA with Odor as a between-subject factor and Time (start, after stress induction and end of the training session) as a within-subject factor was conducted on STAI-Y1 and POMS-SF scores. Both HRV (lnRMSSD, lnHF) and SCL data were analyzed with mixed ANOVAs, with odor condition as between-subject factor and Time as within-subject factor. Analyses were conducted separately for day 1 and day 2. Three participants (one per odor condition) were excluded from the analysis on day 2 due to missing data.

## 3. Results

### *3.1. Demographics and clinical characteristics*

The total final sample was composed of 48 women (age mean = 22.4, SD = 2.2). No significant differences were reported for the different odor groups regarding age, education, state of mindfulness, and social anxiety before starting the treatment. Hence, these variables were not included as covariates in subsequent analyses. The descriptive statistics of the demographic and psychological variables are reported in Table 2.

### *3.2. The effect of the mindfulness treatment on self-report measures*

On day 1, the mixed ANOVA revealed a main effect of Time for both STAI-Y1 ($F_{(1,42)} = 32.85$, $p < .001$, $\eta_p^2 = 0.42$; Fig. 2, Panel A) and POMS-

**Table 2**
Demographic and psychological characteristics of the participants included in the three odor condition groups (happiness BO, fear BO and clean air).

| Variable | Happiness BO (n = 16) | Fear BO (*n* = 16) | Clean air (n = 16) | p* |
|---|---|---|---|---|
| Age (years) | 22.7 (2.36) | 22.0 (2.35) | 22.4 (2.00) | 0.67 |
| Education (years) | 16.4 (1.78) | 15.3 (1.85) | 15.3 (3.09) | 0.22 |
| SMS | 63.31 (12.92) | 68.94 (15.03) | 68.31 (13.51) | 0.46 |
| LSAS | 66.8 (13.02) | 65.3 (10.92) | 64.8 (8.73) | 0.89 |

*Notes*. Data are reported M (SD). *Calculated with ANOVAs.

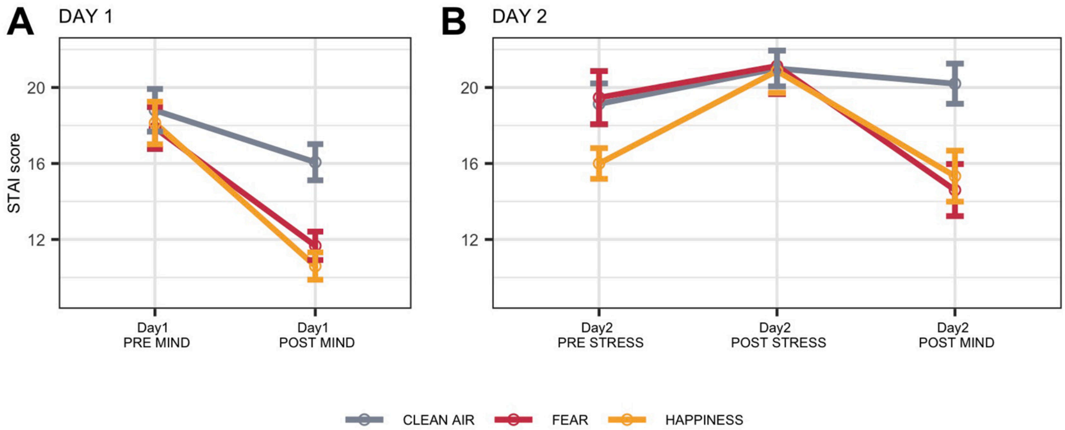


**Fig. 2.** Panel A. STAI score on the first day of mindfulness training in the three odor groups (clean air, fear body odor and happiness body odor) collected before the start of the training (PRE MIND) and after the training (POST MIND). Panel B. STAI score on the second day of mindfulness training in the three odor group (clean air, fear body odor and happiness body odor) collected before the stress induction (PRE STRESS), after the stress induction (POST STRESS) and after the training (POST MIND). Error bars represent ± standard deviation.

SF ($F_{(1,42)} = 18.98$, $p < .001$, $\eta_p^2 = 0.31$), showing a reduction in the anxiety level and mood disturbance after the mindfulness training regardless of the odor condition.

On day 2, the mixed ANOVA on STAI-Y1 revealed a main effect of Time ($F_{(2,84)} = 11.61$, $p < .001$, $\eta_p^2 = 0.22$), and an interaction Time × Odor ($F_{(4,84)} = 2.98$, $p = .024$, $\eta_p^2 = 0.12$). Both in the group performing the mindfulness training in the fear BO condition and in the one performing the training in the happiness BO condition the anxiety level was significantly lower after the mindfulness training compared to their anxiety level after the stress induction (happiness BO, $p = .006$; fear BO, $p < .001$). However, no reduction in anxiety level was observed in the group performing the training in the clean air condition ($p = 1.00$) (Fig. 2, Panel B). The mixed ANOVA on POMS-SF showed no significant main effects of time ($F_{(2,84)} = 1.79$, $p = .18$, $\eta_p^2 = 0.04$), odor ($F_{(2,42)} = 0.58$, $p = .18$, $\eta_p^2 = 0.02$), or interaction ($F_{(4,84)} = 0.66$, $p = .62$, $\eta_p^2 = 0.03$). See Table 3 for mean and standard deviations of POMS-SF and STAI-Y1 at different time points.

### 3.3. The effect of the mindfulness treatment on physiological measures

Regarding lnRMSSD, on day 1, the mixed ANOVA did not reveal any significant main effects or interaction (all ps > .57). On day 2, the mixed ANOVA yielded a main effect of Odor ($F_{(2,42)} = 4.23$, $p = .021$, $\eta_p^2 = 0.17$), and an interaction Time × Odor ($F_{(6,126)} = 2.20$, $p = .048$, $\eta_p^2 = 0.095$). However, no significant differences emerged from the Tuckey HSD post-hoc test (Fig. 3, Panel A). However, for the Odor main effect, the Tukey HSD post-hoc test revealed that the group in the fear BO condition showed significantly lower lnRMSSD values than the group in the clean air condition ($p = .016$), whereas no difference emerged between the group in the fear BO condition and the happiness BO condition ($p = .239$), as well as between the happiness BO condition and the clean air condition ($p = .427$), as shown in Fig. 3, Panel B.

Regarding the lnHF, on day 1, the mixed ANOVA did not reveal any significant main effects or interaction (all ps > 0.57). On day 2, the mixed ANOVA revealed a statistical trend of the main effect of Odor ($F_{(2,42)} = 3.11$, $p = .055$, $\eta_p^2 = 0.13$), with tendentially lower lnHF values in the group in the fear BO condition compared to the clean air condition ($p = .066$), but not in the group in the happiness BO condition vs. the clean air condition ($p = .942$) or in the group in the fear BO condition vs. the group in the happiness BO condition ($p = .131$).

Regarding the SCL, on day 1, the mixed ANOVA revealed only a Time main effect ($F_{(3,69)} = 12.68$, $p < .001$, $\eta_p^2 = 0.35$). On day 2, similarly to day 1, the mixed ANOVA yielded only a Time main effect ($F_{(3,78)} = 8.59$, $p < .001$, $\eta_p^2 = 0.25$). On both day 1 and day 2, no significant Odor main effect or Time × Odor interaction was noted (all ps > .13).

## 4. Discussion

At the level of subjective experience, the results were only partially in line with our hypotheses in that individuals with social anxiety who practiced mindfulness while exposed to emotional BOs (both happiness and fear) experienced a significant reduction in anxiety symptoms, compared with more modest reductions seen in the group that practiced mindfulness while exposed to clean air. The anxiety reduction when exposed to happiness BO is consistent with our hypothesis and with previous research showing that positive BO has a congruent impact on the receiver's responses (Chen and Haviland-Jones, 2000; de Groot et al., 2015a, 2015b; Ortegón et al., 2022). In addition, the inclusion of the fear BO condition enabled us to disentangle the specific role of emotional BOs in modulating the effect of a mindfulness training, given the well-known role of fear BO on both subjective and physiological responses in receivers (de Groot and Smeets, 2017). Interestingly, individuals

**Table 3**
Mean and standard deviation of STAI-Y1 and POMS-SF at different time points: before the start of the training (PRE MIND), after the training (POST MIND), before the stress induction (PRE STRESS), after the stress induction (POST STRESS) and after the training (POST MIND).

| | Day1 PRE MIND | | Day1 POST MIND | | Day2 PRE STRESS | | Day2 POST STRESS | | Day2 POST MIND | |
|---|---|---|---|---|---|---|---|---|---|---|
| | POMS | STAI | POMS | STAI | POMS | STAI | POMS | STAI | POMS | STAI |
| Clean air | 8.40 (23.26) | 18.80 (7.52) | 3.13 (17.50) | 16.07 (6.39) | 4.33 (18.69) | 19.13 (7.24) | 7.07 (18.76) | 21.00 (6.31) | 6.60 (15.59) | 20.20 (7.09) |
| Fear BO | 9.80 (16.56) | 17.87 (7.41) | 1.07 (13.61) | 11.67 (5.02) | 6.27 (18.92) | 19.47 (9.38) | 6.87 (19.09) | 21.13 (9.95) | 2.20 (16.84) | 14.60 (9.19) |
| Happiness BO | 6.33 (15.94) | 18.13 (7.52) | −4.33 (12.33) | 10.60 (4.82) | 0.60 (18.92) | 16.00 (5.42) | 3.20 (10.18) | 20.87 (7.67) | −1.47 (14.46) | 15.33 (9.00) |

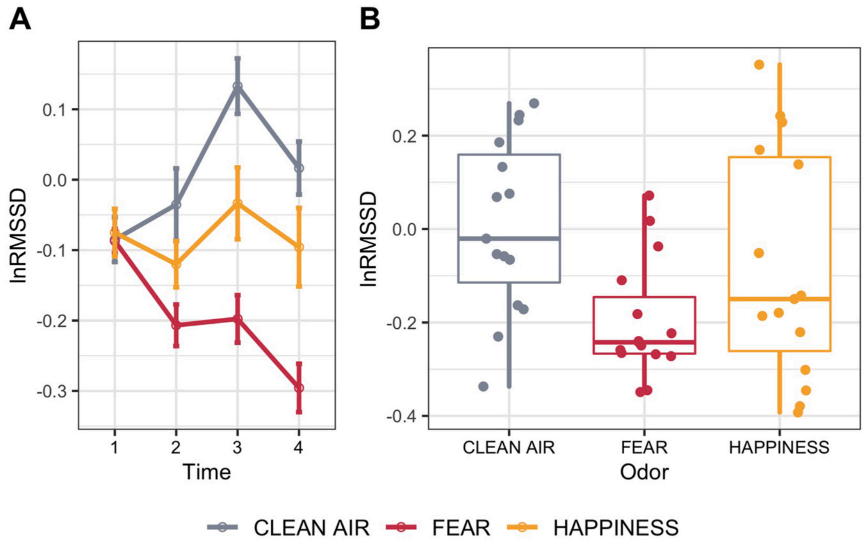


**Fig. 3.** Panel A. Mean lnRMSSD values change during the mindfulness training in the three odors group (clean air, fear body odor, happiness body odor). Units are lnRMSSD values changes from 3 min baseline. Error bars represent ± standard deviation. Panel B. Mean lnRMSSD values in the three odor groups (clean air, fear body odor and happiness body odor) during the second day of mindfulness intervention. The plot shows the median (indicated by the horizontal band), the first through the third interquartile range (the vertical band) of the lnRMSSD in each group. Each dot represents one participant. Units are lnRMSSD values changes from 3 min baseline.

performing the mindfulness while exposed to the fear BO reported symptom reductions that were comparable to the group exposed to the happiness BO. Thus, at a subjective level, the present results contradict the "emotional contagion" hypothesis, which suggests that exposure to negative BOs induces anxiety and negative affect (Albrecht et al., 2011; de Groot et al., 2012; De Groot et al., 2014b; de Groot et al., 2015b; de Groot et al., 2015a).

However, it is important to consider that for the current study, BOs were used as a contextual element during mindfulness, whereas previous studies have focused on subjective, behavioural, and physiological responses to such odors alone or in the context of laboratory-designed tasks, such as passive viewing of faces with matching emotions (Calvi et al., 2020; de Groot, Smeets, Rowson, et al., 2015; de Groot and Smeets, 2017). One possible explanation for these results may be that, subjectively, BOs are primarily processed as social stimuli, conveying the social presence of another individual (Cecchetto et al., 2020; Cecchetto et al., 2019a, 2019b), rather than the specific emotion. Hence, this could have contributed to the positive outcomes of the mindfulness intervention, as being in the presence of others is known to enhance positive experiences (Devereux and Ginsburg, 2001; Garcia-Marques et al., 2021). This interpretation may, at first glance, seem counterintuitive given the aetiology of social anxiety disorders (Moscovitch, 2009). However, whilst many social interactions are anxiety-inducing for individuals with social anxiety, these individuals have been shown to exhibit increased positive affect in the presence of others as opposed to spending time alone (Goodman et al., 2021). Furthermore, research has demonstrated that the processing of human BOs involves the activation of specific brain regions that are specialized in processing socio-emotional information (e.g., inferior frontal gyrus), as well as brain networks involved in attention (e.g., middle frontal gyrus) and emotion regulation (e.g., cerebellum; Dal Bò et al., 2020; Lübke et al., 2014; Lundström and Olsson, 2010; Pause, 2012). Interestingly, the same brain circuits are involved in mindfulness meditation (Tang et al., 2015). Thus, including a social stimulus whilst practicing such interventions may further engage brain regions involved in developing a state of mindfulness. However, more research is necessary to explore these hypotheses.

However, happiness BO did not have any impact on physiological responses. Instead, it was the exposure to the fear BO that resulted in decreased vagally-mediated HRV indices during the mindfulness, indicating an inadequate response to environmental stressors that require a fight or flight reaction. The reduced vagal tone observed during the mindfulness training while exposed to the fear BO is in line with previous studies indicating that fear BO can decrease vagal tone (Ferreira et al., 2018), suggesting that individuals adopt escape behaviours and activate their defensive motivational system (Lang et al., 1990). In the animal kingdom, fear chemosignals serve as warning signals that increase vigilance and affect physiological responses in receivers (Wyatt, 2003). Similarly, negative BOs in humans can act as indicators of potential environmental threats, which can induce adaptive physiological responses to handle dangerous situations.

The divergence between the subjective experiences reported by the participants exposed to happiness or fear BOs and their differential physiological responses can lead to important insights into the role of fear and happiness BOs that clearly require further scrutiny. One possible explanation for this dissociation is that physiological responses are more automatic and do not require conscious awareness of stimuli (Cacciopo et al., 2000). It is likely that, in this context, the fear BO was strong enough to modulate the vagal tone, especially in individuals with social anxiety symptoms who are known to be hypersensitive to negative social stimuli (Staugaard, 2010). In contrast, positive BOs are less researched, harder to produce in laboratory settings, and may have a less automatic physiological effect or require longer exposure, as they do not have immediate survival implications (Pratto and John, 1991).

Crucially, the analysis of odor ratings showed that the three odor conditions were perceived as similar in intensity, pleasantness and familiarity. This indicates that the present results are likely not attributed to perceptual differences between the three conditions and supports previous research showing that the effect of emotional BOs appears independent from conscious recognition (Cecchetto et al., 2020; de Groot et al., 2017; Parma et al., 2017). Indeed, chemical molecules can freely disperse in the air as they are resistant to physical and time barriers (Zelano and Sobel, 2005). These features make emotional BOs suitable to be presented in conjunction with psychological therapies.

When interpreting our findings, some limitations should be noted. First, the small sample size, consisting only of women, limits generalizability to men. However, we specifically included only women to reduce gender-related effects. Second, while the short mindfulness intervention yielded promising results, more sessions could have provided more consistent and ideally long-term benefits. Third, we introduced a stress-inducing task on the second day of the intervention, which prevented us from comparing the two consecutive days of the intervention. However, the intervention was performed after the stress induction to avoid participant drop-out. Furthermore, it is uncertain whether the present findings were influenced by the specific emotion that each BO intended to convey, or if they were primarily linked to a general social presence conveyed by BOs that amplified the social context. To explore this, future studies should include a non-emotional BO condition to further disentangle whether the observed effect was due to the social context transmitted by the BOs or the specific emotions being conveyed.

In summary, this study is the first to use emotional BOs as a catalyst for a psychological treatment, indicating that BOs can be a potential tool for improving a brief mindfulness training for social anxiety symptoms. If these findings are replicated and built on, enhancing a 'social presence' through BOs may also open up avenues within other therapies, such as improving the ecological validity of exposure therapies, or using approach-related BOs to support behavioural activation treatments. The present findings are therefore not only encouraging but also timely, given the growing challenges posed to our mental health systems across the globe.

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## Declaration of competing interest

The authors declare that they have no conflict of interest.

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## Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jad.2024.10.088.

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