Human Body Odors Modulation on Affective Processing of Social-Emotional Virtual Environments

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Abstract. The link between the olfactory and affective systems in humans has been explored in clinical and non-clinical populations. Specifically, there is evidence indicating that both artificial scents and human body odors (HBOs) can influence individual affective processing. Research on HBOs has primarily concentrated on the appraisal of emotional faces, while their effects on other social stimuli are still being investigated. In particular, social-emotional situations can evoke various reactions in humans, and it is essential to examine HBOs' role in their affective processing. Virtual reality facilitates this research by allowing the reproduction of standardized and realistic social-emotional situations. In this study, we investigated whether exposure to emotion-related HBOs (happy, fear, and neutral state) modulates the affective processing of social-emotional situations compared to the absence of exposure. Three social-emotional virtual environments (VEs) designed to elicit positive, negative, and neutral affectivity were tested. During the VE experiences, the experimental group was exposed to HBOs (n=77), while the control group experienced them without HBOs (n=72). Participants were required to rate individual valence and arousal after each social-emotional VE. Findings revealed that HBO exposure overall resulted in lower arousal ratings and higher valence ratings than the control group. The difference in valence rating was particularly evident in the negative VE. This demonstrates the modulating effect of HBOs on the affective processing of social-emotional VEs. Future directions include investigating differences across emotion-related HBOs in the affective processing of social-emotional situations.

Keywords. Human body odors; virtual environment; emotion; social stimulation; affective processing

1. Introduction

An expanding corpus of research underscores the influential role of olfactory stimuli in shaping the dynamics and outcomes of social interactions among humans. Investigations have delved into the intricate mechanisms through which human behavioral responses within social-emotional contexts are modulated by both synthetic [1] and naturally occurring odors [2]. This body of literature elucidates the interplay between olfactory cues and social behavior, shedding light on how scent perception modulates human social dynamics and decision-making processes. By directing attention toward human body odors (HBOs), individuals can convey socially pertinent information, including indications of cooperation, aggression, and competition, through chemosensory signals [3, 4]. For example, a study suggests that HBOs associated with fear can induce heightened anxiety among recipients by intricately modulating their negative perceptions of social stimuli experienced within immersive virtual reality environments [5]. Given the olfactory system's capacity to exert influence over individual affective processing, HBOs emerge as a pivotal point within the realm of social neuroscience, as they can convey numerous social cues. Thus far, attention has predominantly been directed toward investigating emotion elicitation based on socially pertinent stimuli such as facial

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images and videos [4]. However, little has been studied on how the HBOs modulate affective processing in relation to other social-emotional stimuli. Within this lacuna, the virtual reality methodology assumes prominence, offering a means to replicate social-emotional scenarios within controlled environments that afford participants a heightened sense of presence and immersion.

Considering the above, we have developed social-emotional virtual environments (VEs) that seek to elicit positive, negative, or neutral affectivity [6, 7]. This study aims to investigate the potential influence of HBOs on affective processing within social-emotional VEs, with emotional self-reports as the primary assessment metric.

2. Methods

2.1. Participants

The study included 149 adults aged 18 to 55 years in two groups. Participants took part in the study in exchange for monetary rewards. Participants were randomly split into two groups: the experimental group exposed to HBOs (n=77) and the control group not exposed to HBOs (n=72). Participants belonging to the experimental group were 36 males and 41 females (M = 34.02; SD = 10.89). Participants belonging to the control group were 32 males and 40 females (M = 33.68; SD = 9,38).

Participants were Spanish-speaking, not pregnant, non-smokers, and were not taking any psychiatric medication. Before participating in the study, informed written consent was given. The study has been approved by the Ethical Committee of the Polytechnic University of Valencia (P2_18_06_19).

2.2. Human body odors

The HBOs used for the present study were previously sampled through donors' armpit sweat at the Institute of Applied Psychology (Lisbon, Portugal). Specifically, pads were applied directly to donors' bodies to soak up the sweat they released while watching emotional-laden videos. The exposure to these videos was part of an emotional induction procedure intended to elicit emotional states of happiness, fear, and neutrality, respectively. The induction of these emotional states was analyzed by filling out self-report questionnaires, which assessed their levels of anger, fear, happiness, sadness, disgust, neutrality, surprise, calmness, and amusement using 7-point Likert scales, ranging from 1, indicating "not at all," to 7, indicating "very much." After that, HBOs were created by combining different pads related to the same emotion and stored in a -80°C freezer. Previous studies have been conducted on the sweat sample collection and conservation method [8].

During the odor exposure procedure, HBOs were released through a purposely developed 3-channel olfactometer (with airflow distributed through nose-positioned vials), which dispensed odors from pads at a controlled and gradual flow rate of 50ml/min, which was also used in previous studies [8]. The olfactometer was connected to an air compressor. Clean air was proportioned for a few seconds between odor administration to remove residual odor remaining in the machine.

2.3. Virtual environments

The VEs in this study were specifically adapted for a semi-immersive CAVE system. Concretely, three social-emotional VEs were modeled with Unity 3D® software to convey positive, negative, or neutral affectivity. The VEs had the same layout with a stable number of park elements and virtual agents between park conditions. They consisted of three different "emotional" parks trying to convey affectivity through visual and acoustic stimuli (see Figure 1). Each emotional VE lasted 60 seconds, and social stimulation was presented for 30 seconds. This social stimulation used virtual agents to convey social meaning. The virtual agents were pre-programmed avatars with human appearances. Further details regarding the VEs are specified in prior publications [6, 7].

Figure 1: Positive VE. a. non-social; b. social

2.4. Procedure

Within a broader experimental methodology, useful data were collected for this study. Before the experimental testing, the Liebowitz Social Anxiety Scale (LSAS) and the Beck Depression Inventory (BDI) were administered to rule out the risk for depression and social anxiety in both groups. Moreover, the olfactive sensitivity of participants in the experimental group was screened via the Discrimination and Thresholds subtests of the Sniffin' Sticks Test [9]. Afterward, participants were individually exposed to the three VEs in a counterbalanced order. Only the experimental group (*n*=77) was exposed to three fear, happiness, and neutral HBOs while watching the three VEs. HBOs were administrated in a pseudorandomized order across participants. After experiencing each VE, participants were asked to self-report two canonical dimensions of affect, emotional valence and arousal, on a visual 9-point Likert scale. These measures were taken from the Self-Assessment Manikin [10]. In the valence scale, the "0" pole represented the highest negativity, and the "9" pole represented the highest positivity. In the arousal scale, "0" represented minimal activation, and "9" represented maximum activation.

2.5. Data analysis

Data analyses were performed using IBM SPSS Statistics v25. A generalized linear mixed model (GLMM) approach was used to compare self-reported valence and arousal responses. Analyses specified a Gaussian distribution with a log-link function and a robust standard estimator. After running the Kolmogorov-Smirnov test, a log-link function was chosen to be applied, which is suitable for modeling data that deviate from normality as the current data. The subjects' ID was included as a random factor with random intercepts. The analysis accounted for VE and group (HBO, non-HBO) as fixed factors for valence and arousal reports (1 + VE + GROUP + VE * GROUP + (1|subject)). Post hoc analyses were run using Bonferroni correction.

3. Results

Table 1: Means and standard deviations of valence and arousal reported by groups in the three emotional VEs.

Affect dimension	VE	GROUP	N	Mean	SD
Valence	Positive	HBO	77	7.299	1.940
		non-HBO	72	7.111	1.968
	Negative	HBO	77	4.130	2.041
		non-HBO	72	3.264	2.295
	Neutral	HBO	77	6.026	1.899
		non-HBO	72	5.570	1.774
Arousal	Positive	HBO	77	3.312	2.358
		non-HBO	72	4.292	2.417
	Negative	HBO	77	4.909	2.202
		non-HBO	72	5.597	2.448
	Neutral	HBO	77	2.857	1.890
		non-HBO	72	3.194	1.933

Table 1 presents the means and standard deviations of valence and arousal as reported by the groups across the three emotional VEs.

Results showed significant main effects of VE in valence, $F(2, 443) = 225.84$, $p < .001$ and arousal, $F(2, 443) = 149.78$, $p < .001$. In particular, participants' self-reported valence matched the emotional VE types, which was interpreted as a successful manipulation check. Consequently, on average, positive VEs received higher valence ratings compared to the others (negative – neutral: $MD = .603$; $SE = .0334$, $p < .001$; negative – positive: $MD = .486$; $SE = .0259$, $p < .001$; positive – neutral: $MD = 1.242$; $SE = .0564$, $p < .001$). On the other hand, on average, participants reported greater arousal in the negative VE, with the positive and neutral VEs following in that order (negative – neutral: $MD = 1.75$; $SE = .1029$, $p < .001$; negative – positive: $MD = 1.42$; $SE = .0783$, $p < .001$; positive – neutral: $MD = 1.23$; $SE = .0779$, $p = .003$).

There was also a significant effect of the main group factor on valence, $F(1,147) = 10.61$, $p = .001$, and arousal, $F(1, 147) = 6.75$, $p = .009$. Concretely, on average, the HBOs group reported higher valence than the non-HBOs group ($MD = .891$; $SE = .0375$, $p = .001$). The HBOs group also showed, on average, lower arousal ratings than the non-HBOs group ($MD = 1.19$; $SE = .0837$, $p = .009$).

Interestingly, there was also a significant interaction between groups and VE, $F(2,294) = 8.74$, $p = .013$, indicating emotional valence differences in the negative VE. Indeed, the post hoc comparison showed that the group exposed to HBOs during the negative VE reported a higher positive valence than the non-HBOs group ($MD = .739$; $SE = .0661$, $p = .011$). The group * VE interaction regarding arousal did not yield statistical significance, $F(2, 294) = 1.48$, $p = .47$.

4. Discussion

Regardless of group type, the results demonstrate a direct self-reported valence modulation depending on the type of the social-emotional VE and a consistent arousal modulation in the negative and neutral VEs (but inconsistent in the positive VE). This effect was also found in a similar study that did not implement the HBOs [7]. This is consistent with affect attribution theories [11], demonstrating the activation of corresponding emotional responses upon exposure to emotional stimuli. It is in line with findings from affect research indicating a tendency towards negativity bias, where negative stimuli typically evoke greater perceived arousal levels according to self-reports [11]. Furthermore, regardless of social-emotional VEs, findings revealed that exposure to HBOs resulted in lower arousal ratings and higher valence ratings compared to the control group, elucidating the modulating effect of HBOs on the affective processing of social-emotional VEs. This observation aligns with broader studies on HBOs and emotional affective processing, extending beyond the sphere of VEs [12]. Thus, HBOs may mitigate arousal activation by promoting positive responses. Finally, the results indicate that the group exposed to HBOs during the negative VE rated a greater positive valence than the control group. It has been posited that exposure to emotion-related HBOs promotes the illusory presence of others during decision-making [13]. This might indicate that HBOs could activate neural circuits associated with positive social experiences or memories of pleasant interactions, even in negative contexts, favouring a more positive evaluation. This could occur through several mechanisms, such as the unconscious association of odor with positive past experiences or their impact on the limbic system, which regulates emotions and affective responses [1]. A further possible interpretation might be that exposure to HBOs could influence the perception of social-emotional VEs through associative conditioning, attenuating the perception of negativity and inducing greater attention to positive features of the context. Indeed, individuals might unconsciously associate HBOs with rewarding social experiences or feelings of safety and familiarity. As a result, during exposure to HBOs, positive connections might form between odors and social experiences, leading to a more positive evaluation of VE. In alignment with this notion, empirical findings suggest that HBOs influence social-emotional perception, supporting the idea that exposure to HBOs may affect the perception of VEs through associative learning and emotional responses. For example, a study supports that HBOs, a meaningful and rewarding social signal, can influence social-emotional perception through positive associative learning between HBOs and social experiences [14]. Another study showed that fear-related HBO heightened anxiety and reduced trust towards a virtual character, indicating that their impact may influence social information processing and impression formation in VEs [5].

Based on these findings, it is recommended that future research investigate variations in emotion-related HBOs and their impact on the affective processing of social-emotional scenarios. Namely, investigating which type of HBO influences a certain social-emotional situation and why. In general, future studies should explore the influence of HBOs on VEs, employing objective methodologies such as electroencephalography or galvanic skin response. Furthermore, examining potential discrepancies in HBO effects within social and non-social contexts would be pertinent. This study's limitations could encompass subjectivity bias in self-reports, wherein participants may demonstrate response bias or social desirability bias, thereby impacting their responses and potentially distorting the results. Consequently, HBO effects are expected to be more evident when employing implicit measures, such as psychophysiological activity.

5. Conclusion

The extensive research on HBOs underscores their significant role in shaping human social interactions and behavioral responses in general [2-5]. With HBOs linked in social neuroscience, virtual reality methodologies are suggested for understanding how these signals interact with social-emotional stimuli, suggesting their potential to induce affective responses. This work aimed to evaluate how individuals process social-emotional VEs when exposed to non-specific human HBOs. This was accomplished by analyzing self-reported responses on the degree of perceived valence and arousal in each experimental condition.

In synthesis, the social-emotional VEs were found effective in eliciting positive, negative, and neutral affections, as measured by self-reports. In addition, despite the social- emotional VEs, exposure to HBO led to reduced arousal ratings compared to the control group. However, HBOs increased self-reported valence, mitigating, in particular, the negative responses to negative VEs and revealing the role of odors in modulating emotions and affective responses.

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