Olfactory-induced Positive Affect and Autonomic Response as a Function of Hedonic and Intensity Attributes of Fragrances

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Abstract— **Olfactory perception is intrinsically tied to emotional processing, in both behavior and neurophysiology. Despite advances in olfactory-affective neuroscience, it is unclear how separate attributes of odor stimuli contribute to olfactory-induced emotions, especially within the positive segment of the hedonic dimension to avoid potential cross-valence confounds. In this study, we examined how pleasantness and intensity of fragrances relate to different grades of positive affect. Our results show that greater odor pleasantness and intensity are independently associated with stronger positive affect. Pleasantness has a greater influence than intensity in evoking a positive vs. neutral affect, whereas intensity is more impactful than pleasantness in evoking an extreme positive vs. positive response. Autonomic response, as assessed by the galvanic skin response (GSR) was found to decrease with increasing pleasantness but not intensity. This clarifies how olfactory and affective processing induce significant downstream effects in peripheral physiology and self-reported affective experience, pertinent to the thriving field of olfactory neuromarkerting.**

Index Terms—**Behavioral Modelling, Olfactory Perception, Affect, Autonomic Response**

I. INTRODUCTION

Olfaction and affect are intrinsically coupled. Exposure to pleasant odors can elicit autonomic and neurophysiological changes [1],[2], as well as self-reported positive emotional responses [3]. This intertwining stems from the interconnected neuroanatomy underlying olfactory and affective processing. The olfactory regions–entorhinal cortex and orbitofrontal cortex (OFC)—have bidirectional neuronal pathways with subcortical affective centres, especially the amygdala and hippocampus [4]. Having discovered these structural connectivities, the functional specifics of how olfactory perception come to elicit emotional responses, at both the behavioral and neurophysiological level, is a topic of significant research interest.

Classical theories often describe emotion-inducing stimuli in terms of two dimensions: hedonic and intensity value [5]. Hedonics refers to the pleasantness-unpleasantness continuum, while intensity refers to the high-low intensity continuum. These dimensions are often assumed to be independent attributes of emotional stimuli, supported by dissociation evidence suggesting that odor hedonics are coded in the OFC, while odor intensity is coded in the amygdala [6]. However, more recent studies challenge this simplistic view. The amygdala responds not just to odor intensity, but also to the spectrum of hedonic value [7]. Moreoever, there is neural interaction between intensity and hedonic processing: Higher intensities of odors evoke higher amygdalar activations than lower intensities, only if the odors are positive or negative but not neutral [8]. This suggest that hedonics and intensity are not processed as independently as classical theories assume them to be.

Despite such progress in olfactory-affective neuroscience, there remains outstanding issues to be examined: (i) Understanding of the neural overlaps of olfactory and affective processing does not fully predict how odor hedonics and intensity translate to the downstream effects in peripheral physiology and self-reported affective experience. Convergence in neural coding may not necessarily manifest as integrated effects in autonomic and subjective response. This warrants its own behavioral investigation. (ii) The majority of olfactory research compare pleasant vs unpleasant valence types, with few studies focusing on how gradations within a valence type (e.g. different levels of pleasantness) combine with intensity to give rise to affective response. Indeed, some have suggested that weakly presented unpleasant stimuli often have significantly greater perceived intensity than strongly presented pleasant ones [9], potentially confounding many research findings based on the pleasant-to-unpleasant methodology. This motivated us to focus on the pleasant section of the hedonic dimension. Such an approach would be informative to the thriving field of olfactory neuromarketing, which is concerned with the design of pleasant odors to engage customers.

To address these gaps, in this study, we model the relative contributions of odor pleasantness and intensity of fragrances, in contributing to (i) different grades of subjective positive emotional response and to (ii) autonomic physiological reaction measured via galvanic skin response (GSR). This provides a novel, functional quantification of how perceptual attributes of pleasant stimuli lead to downstream outcomes, complementing our understanding of the neural mechanisms linking olfactory perception to response.

II. METHODS

A. Experimental Protocol

Thirty-four subjects (age range 21–42) participated in this study, approved by the Institution Review Board (IRB) of

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National University of Singapore. All subjects were females, to avoid data heterogeneity due to gender differences [10]. There were two sessions of the study. The first session was a pre-screening to determine, out of an array of six pleasant fragrances of fixed concentration, the two most-loved and two least-liked fragrances (for variability in behavioral and physiological responses). In the second session, subjects were blindfolded and the four selected fragrances were presented for 10 trials each, totaling 40 trials throughout the experiment. The order of fragrance presentations was randomized across the experiment. In each trial, a fragrance was presented for 8 seconds, followed by behavioral measures (below), and then a sample of coffee to neutralize the fragrance. Trials were interleaved by short breaks, to allow the recent fragrance to dissipate and minimize odor masking effects. Throughout the experiment, GSR data was also acquired successfully from the left index and middle fingers of 23 of the subjects , recorded using a Shimmer3 GSR Unit (Dublin, Ireland). The sampling rate of the GSR signal was 512 Hz.

After the first, fifth and tenth presentation of each fragrance, subjects rated pleasantness and intensity, both on a scale ranging from 0 to 10 (0 = low pleasantness/intensity, 10 = high pleasantness/intensity). They also indicated which of five emotional responses most closely reflected their experience during fragrance presentation (1 = positive surprise, 2 = happy, 3 = thinking, 4 = disgust, 5 = negative surprise).

B. GSR Data Analysis

1) Preprocessing: Discontinuities and baseline shifts in the GSR signal were visually identified. Discontinuities were treated with linear interpolation of the uncorrupted data points from before and after discontinuities. Next, sudden baseline shifts were corrected, before the signal underwent a 64-order low-pass filter with 0.5 Hz cutoff.

2) Inferring Sympathetic Nervous System Activation: Recorded GSR signal can be represented as a summation of a slow varying tonic component and a fast varying phasic component as follows: $y(t) = y_p(t) + y_s(t)$, where $y_p(t)$ and $y_s(t)$ are the constituent phasic and tonic components, respectively. $y(t)$ represents the recorded GSR signal. The tonic component $y_s(t)$ is related to thermoregulation and general arousal of an individual. The phasic component $y_p(t)$ can be thought of as the physiologically smoothed version of the sympathetic nervous system (SNS) activity, i.e., convolution between the sparse impulsive SNS activity and physiological system (related to sweat gands and skin) response [11]. The convolution is as follows: $y_p(t) = h(t) * u(t)$, where $h(t)$ is the physiological system response and $u(t)$ is the sparse impulsive SNS activity which can be modelled as $u(t) = \sum_{i=1}^{N} q_i \delta(t - \Delta_i)$, where q_i is the impulse amplitude, and Δ_i is the impulse timing. Studies (e.g. [12]) used state-space equations to model physiological dynamics involving a sparse impulsive input and formulated optimization problem for deconvolution; and proposed a coordinate descent based deconvolution approache to solve for the sparse impulsive input $u(t)$ as well as recover the physiological system response $h(t)$. Inspired by this, we use a state-space based deconvolution approach in order to identify the sparse impulsive SNS activity $u(t)$ similar to [13]. We recover $u(t)$ with 1 Hz sampling resolution.

3) Sympathetic Arousal State Estimation: We use the state-space formulation in [13], [14] relating arousal to the probability of SNS impulse occurrence in the recovered $u(t)$. Based on the proposed arousal estimation scheme in [13], we estimate the probability of SNS impulse occurrence (p_j) for each time point. The average p_j values during the 8-seconds fragrance presentation window of each trial was calculated, to give us GSR Impulse Probability.

III. Results

A. Modelling Olfactory-induced Affect

A small number of behavioral trials (15) with technical issues were discarded. Across valid trials (N = 407), majority (85.7%, n = 349) of emotional responses were neutral (Thinking), positive (Happy) or extreme positive (Positive Surprise), shown in Fig 1A. As this study focuses on positive affect, so the minority of unexpected negative responses (10.8%) were excluded from further analyses. The behavioral ratings were then grouped by the 3 emotion responses (Fig. 1B). Trend analyses reveal a decreasing linear + quadratic trend for pleasantness, $t(346) = -7.39, p < .001$ and $t(346) = -4.07, p < .001$ respectively; this means that the decrease in pleasantness between Positive Surprise and Happy responses is smaller than that between Happy and Thinking responses. Meanwhile, intensity showed a linear-only trend, $t(346) = -3.12, p = .002$, signifying a similar-sized decrease in intensity from Positive Surprise to Happy to Thinking response.

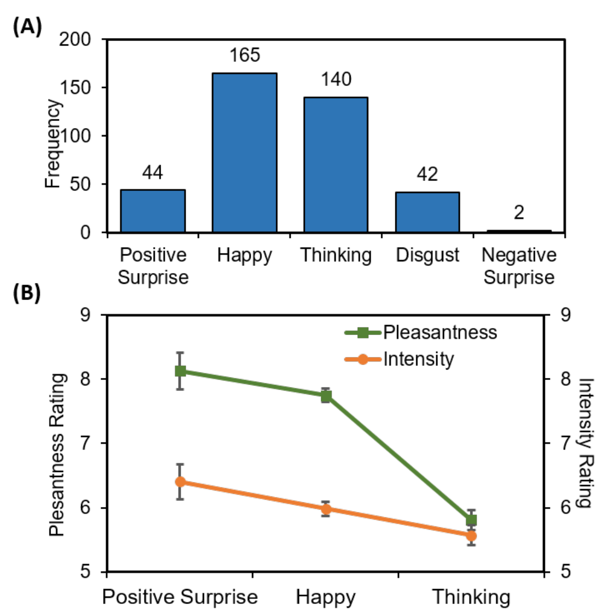

Fig. 1. (A) Histogram of the 5 emotional responses, with the frequencies labelled; (B) Pleasantness and Intensity scores for the three neutral-to-positive responses. Error bars indicate ±1 standard error.

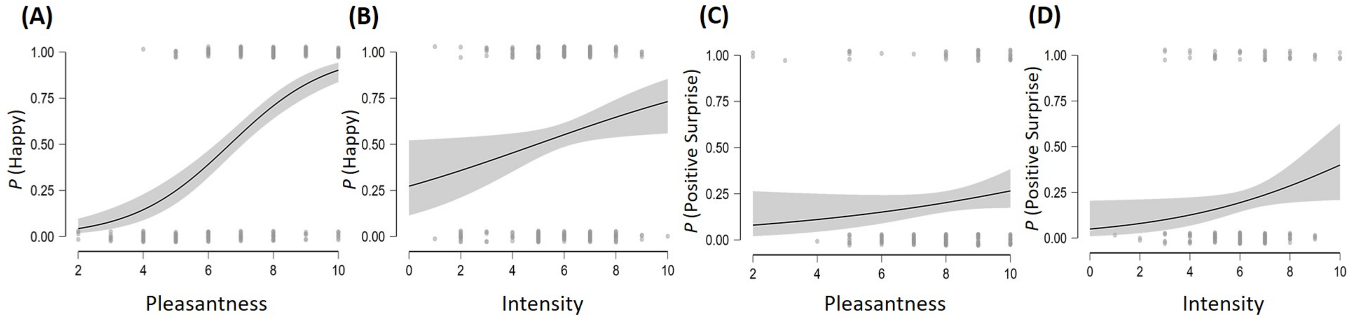

Fig. 2. Binary logistic regression plots on effect of (A) pleasantness and of (B) intensity, on probability of evoking a Happy response (rather than Thinking response); and plots on effect of (C) pleasantness and of (D) intensity, on probability of evoking a Positive Surprise response (rather than a Happy response). Dots are individual data-points, and grey bounds represent 95% confidence intervals.

Pleasantness and intensity were not correlated, $r(347) = -0.035, p = .52$. This means that their similarly decreasing patterns across emotional responses (Fig. 1B) are not due to any hedonic-intensity dependencies. Thus, hedonics and intensity are independently contributing to the heightening of emotional responses, and so was modelled below:

1) Distinguishing Neutral From Positive Responses: A binary logistic regression on Happy vs Thinking responses was run, with Pleasantness and Intensity as predictor variables. Replicate (whether pleasant odor was presented for 1st, 5th or 10th time) and Fragrance Identity (type of fragrance used) were entered as covariates to be statistically controlled. While controlling for all other variables, the type of emotional response evoked can be predicted by Pleasantness, $\chi^2(1) = 60.49, p < .001$, as well as by Intensity, $\chi^2(1) = 4.95, p = .026$. The overall logistic model is:

$$log\frac{P(Happy)}{P(Thinking)} = -5.56 + (0.67\times\text{PL}) + (0.19\times\text{IN})$$

For every unit increase in pleasantness, the odds of the fragrance evoking a Happy over a Thinking response increases by 94.4%. For every unit increase in intensity, the odds of the fragrance evoking a Happy over a Thinking response increases by 21.9%. Therefore, odor hedonics is approximately 4.3 times more impactful than odor intensity in evoking a positive affective response (Fig. 2A, B).

2) Distinguishing Positive From Extreme Positive Responses: Binary logistic regression analysis on Positive Surprise vs Happy responses was conducted, with the same predictors and co-variates. While controlling for all other variables, the type of emotional response evoked can be significantly predicted by Intensity, $\chi^2(1) = 4.27, p = .039$, but only marginally by Pleasantness, $\chi^2(1) = 2.44, p = .12$. This overall logistic model is as follows:

$$log\frac{P(PSurprise)}{P(Happy)} = -3.42 + (0.25\times\text{IN}) + (0.18\times\text{PL})$$

For every unit increase in Pleasantness, the odds of the fragrance evoking a Positive Surprise over a Happy response increases by a marginal 19.5%. For every unit increase in Intensity, the odds of the fragrance evoking a Positive Surprise over a Happy response increases by a significant 29.0%. In evoking more extreme positive affect, intensity is 1.5 times more impactful than pleasantness (Fig. 2C, D).

B. Modelling Galvanic Skin Response

ANOVA analysis showed that GSR impulse probability, averaged across all trials and subjects, was not significantly different across emotional responses, $F(2, 219) = 0.503, p = .61$. No trends were observed, $p's > .05$ (Fig. 3A). Next, a multiple linear regression (MLR) was conducted, testing GSR Impulse Probability as the outcome variable and Pleasantness and Intensity as predictor variables. Emotional Response was tested for moderation, and Replicate and Fragrance Identity were controlled as co-variates. After controlling for all other variables, Pleasantness was a significant predictor of GSR Impulse Probability, $t(216) = -2.39, p = .018$, but intensity was not, $t(216) = -0.34, p = .73$. The standardized MLR model is as follows:

$$GSR_{ImpulseProb} = (-0.19\times\text{PL}) + (-0.02\times\text{IN})$$

For every standard deviation (SD) increase in Pleasantness, the GSR Impulse Probability during fragrance exposure decreases by 0.19 SD (Fig. 3B). Emotion was not a significant moderator, $t(216) = -1.63, p = .11$, so the above relationship holds across emotional responses.

IV. Discussion

In this study, we sought to quantitatively characterize the influence of hedonics and intensity of pleasant-only odors on (i) positive affective experience, and (ii) autonomic response. This has lead to the following novel discoveries:

A. Differential Influences Across Grades of Positive Affect

Higher pleasantness was 4.3 times more influential than higher intensity in producing a positive (Happy) response. The reverse is the case for more extreme positive response (Positive Surprize); intensity was the most relevant factor, with its impact being 1.5 times that of pleasantness. This demonstrates the differential and dynamic contributions of odor hedonics and intensity across levels of positive affect. Moreover, these contributions are independent of each other, suggesting that despite neural overlaps in hedonic and intensity processing (e.g. [8]), the perceptual attributes of odors

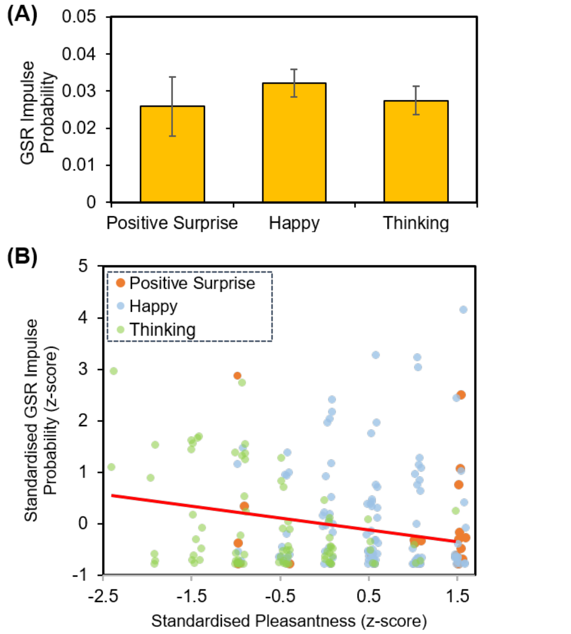

Fig. 3. (A) Average GSR Impulse Probability across the three emotional responses. Error bars indicate ±1 standard error. (B) Standardized regression line of the relation between Pleasantness and GSR Impulse Probability when other variables are controlled. Dots are individual data-points (jittered) across all trials and subjects, colored according to Emotional Response

act independently at the behavioral level within the pleasant hedonic range.

B. Pleasantness, but not Intensity, reduces Skin Conductance

GSR impulse probability decreases with increasing pleasantness, while intensity has little effect. Pleasant odors can retrieve positive memories and associations [15], thereby mellowing sympathetic arousal [16]. Concerning intensity, the results are in contrast with prior research suggesting that perceptually intense odors elicit more autonomic activation [17]. However, it must be noted that these studies often use a range of pleasant and unpleasant odors, raising the issue again of how opposite-valenced stimuli may have asymmetric subjective scaling for intensity. That is, unpleasant odors can be judged as more intense than pleasant ones [9]; and this couples with observations that unpleasant odors are more likely to elicit sharper physiological reactions [3]. This functional difference can be explained by the fact that pleasant and unpleasant odors are processed differently in the brain [18]. Therefore in the current study, we chose to examine only the positive segment of the hedonic "continuum", thereby avoiding any cross-valence confounds; and in this context, intensity is not a significant factor for fragrance-induced autonomic responses.

V. Conclusions

Our present findings provide a new perspective in understanding the complex relation between olfaction and affect. Furthermore, they have implications in the thriving field of olfactive neuromarketing for developers of cosmetic products and multimedia systems utilising odor to evoke positive experiences. Future research can expand on this work, by investigating how this relationship between pleasant odor attributes and emotional or physiological response, is modulated by multisensory cues in more immersive environments.

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