Beauty is in the Nose of the Beholder: Fragrance Modulates Attractiveness, Confidence and Femininity Ratings and Neural Responses to Faces of Self and Others

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Abstract

Previous research investigated cross-modal influence of olfactory stimuli on perception and evaluation of faces. However, little is known about the neural dynamics underpinning this multisensory perception, and no research examined perception for images of oneself, and others, in presence of fragrances. This study investigated the neural mechanisms of olfactory-visual processing using electroencephalography (EEG) and subjective evaluations of self- and other-images.

22 female participants evaluated images of female actors and themselves while being exposed to the fragrance of a commercially available body wash or clean air delivered via olfactometer. Participants rated faces for attractiveness, femininity, confidence and glamorousness on visual analogue scales. EEG data was recorded and event-related potentials (ERPs) associated with onset of face stimuli were analysed to consider effects of fragrance presence on face processing, and interactions between fragrance and self-other image-type.

Subjective ratings of confidence, attractiveness and femininity were increased for both image-types in pleasant fragrance relative to clean air condition. ERP components covering early-to-late stages of face processing were modulated by the presence of fragrance. Findings also revealed a cross-modal fragrance-face interaction, with pleasant fragrance particularly affecting ERPs to self-images in mid-latency ERP components.

Results showed that the pleasant fragrance of the commercially available body wash impacted how participants perceived faces of self and others. Self- and other-image faces were subjectively rated as more attractive, confident and feminine in the presence of the pleasant fragrance compared to an un-fragranced control. The pleasant fragrance also modulated underlying electrophysiological activity. For the first time, an effect of pleasant fragrance on face perception was observed in the N1 component, suggesting impact within 100 ms. Pleasant fragrance also demonstrated greater impact on subsequent neural

processing for self, relative to other-faces. The findings have implications for understanding multisensory integration during evaluations of oneself and others.

1.1 Introduction

There is a well-established link between self-confidence, self-esteem and self-perceived physical attractiveness, which appears to be particularly robust in women [1,2]. Fragrance has historically been used across cultures to influence a person's appearance and attractiveness [3]. Research has demonstrated the interaction between the olfactory system and other sensory systems such as vision, which creates a unified, meaningful multisensory experience [4]. The presence of odours can provide important contextual or social cues which influence perception of various stimuli via cross-modal multisensory perception [5]. For example, pleasant fragrances can enhance the perceived pleasantness of a virtual reality environment [6], as well as people's perception of art [5], and perception of face images [3,7–12]. These effects are bi-directional; positively or negatively valenced images influence perception of fragrances [13] and congruent visual stimuli can enhance fragrance detection sensitivity [14].

Research has begun to elucidate the cross-modal and multisensory impact of olfactory stimuli on perception of faces. Spence [15] highlights the widespread nature of these effects with the observation that a variety of fragrances have been shown to alter face perception, with significant implications for affective responses and social interactions. In a recent review, Syrjänen et al. [16] conclude that, despite some conflicting findings, the evidence suggests that positive or negative fragrances influence face perception in the direction of valence (i.e., pleasant fragrance increases positive evaluations of faces). Again, fragrance-face cross-modal multisensory perception occurs in a bi-directional fashion, amplifying the intensity of each stimulus; for example, fragrances were rated as more pleasant when paired with a happy, compared to a disgusted face in [12].

Similarly, the cross-modal influence of fragrance valence on perception of facial attractiveness, as well as youthfulness and self-esteem, has been demonstrated across a number of studies [3,8,11,17,18]. There is evidence to suggest that the positive effect of pleasant fragrances on facial attractiveness follows a linear pattern, whereby increasing positive fragrance valence results in increased perceived attractiveness [3,11,17]. Moreover, higher-order associations with specific fragrances, such as gender effects, may modulate the impact of pleasant fragrance on perceived facial attractiveness. For instance, Risso et al. [19] observed that a pleasant caramel fragrance, associated with femininity, enhanced attractiveness of female faces, whilst a 'masculine' liquorice fragrance enhanced attractiveness of male faces. This finding suggests gender-congruence of an odour modulates cross modal influences on person perception [19]. In terms of mechanisms, the enhancement of facial attractiveness caused by pleasant fragrances may be facilitated by the privileged access to affective brain networks by our sense of smell [3]. This is reflected by activation of reward-related cortical structures such as the medial orbitofrontal cortex in response to pleasant fragrance [10,20,21], regions involved in affective processing such as bilateral parahippocampal gyrus and amygdala [22], and integrative cortices such as the anterior cingulate cortex for pleasant and unpleasant fragrances [21]. Although a number of event-related potential (ERP) studies have shown that facial attractiveness can modulate N1 [23,24], P2 [25,26], N2 [25,27] P300 [28,29], late positive complex (LPC; [30,31] and late positive potential LPP [27], to our knowledge, no studies have specifically examined ERPs to facial attractiveness during fragrance presentation.

Although the majority of the research has focused on the influence of fragrances on perception of other's faces, a recent review highlights a growing body of evidence suggesting that fragrance can also impact self-perception Spence [15]. Self-perceived physical attractiveness and self-confidence were enhanced in a sample of men when they had previously applied an active deodorant containing a pleasant fragrance and antimicrobial ingredients designed to reduce malodour, compared to a control body spray with no active ingredients [32]. Women also rated the men in the active deodorant condition as more attractive in dynamic video clips, but not static images. This suggests that self-confidence may have translated into perceptible changes in the men's non-verbal behaviour which influenced observer judgements. Taken together, this research has important implications for social communication, and further exploration of the role of fragrance valence on self-perception is warranted. The majority of research has focused on opposite-sex attractiveness ratings, and there is little evidence to suggest how cross modal perception might influence women's perception of other women's attractiveness.

Despite growing interest in this topic, the neural mechanisms underpinning cross-modal visual/olfactory interactions, particularly the spatio-temporal characteristics of these cross-modal interactions, are not yet well understood [12]. A handful of studies have explored the temporal characteristics of visual/olfactory cross- modal interactions. For example, Cook et al. [11] observed amplitude modulation of late (> 600 ms) and ultra-late (> 900 ms) positive potential ERP components in response to faces with neutral facial expressions presented 3s after a valenced fragrance. In the pleasant fragrance condition, greater negative amplitude to faces was elicited in the LPP component, across right posterior- and temporal-parietal electrodes. Moreover, during ultra-late latency epochs, faces presented in a pleasant fragrance condition elicited greater positivity in left lateral frontal-temporal electrodes. The authors concluded that these findings provide evidence that cross-modal evaluations for fragrance-faces stimuli are represented in the LPP at late stages of processing.

A further study by Cook et al. [12] explored the influence of fragrance valence on perceptions of emotional faces, including happy and disgusted facial expressions. Fragrance-face interactions modulated amplitude at earlier stages of processing in both the N200 and N400 ERP components. Unlike clean air and unpleasant fragrances, which were differentially impacted by face valence, pleasant fragrances modulated ERPs similarly for both happy and disgusted faces. This may demonstrate a broad effect of positively-valenced fragrances, irrespective of the emotion depicted in the face, however, there has been no investigations into whether this effect would cross over to evaluation of self-images. More recently, Syrjänen et al. [16] observed enhanced N170 ERPs to disgusted faces when in the presence of a pleasant fragrance, suggesting that fragrances can bias socioemotional perception during early visual processing. However, early ERP modulation has never been observed in own neutral faces during pleasant fragrance presentation. It is also unclear whether such effects would be applicable across evaluation domains. Whilst odour has been shown to modulate self-perceived attractiveness and self-confidence in previous work (e.g.[32]), other related evaluative dimensions such as femininity and glamorousness are less well studied in the context of pleasant odours, however both are subject to modification/enhancement with other cosmetics such as make-up (e.g.[33]), and thus may capture unique variance in participants' experience of viewing face images.

To our knowledge, the current study is the first of its kind to explore the neural mechanisms of olfactory-visual interactions on perception of facial attractiveness for images of the self, as well as perception of other people's faces. Therefore, the aim of the current study was to investigate the spatio-temporal brain dynamics underpinning cross-modal interaction between simultaneous presentation of a fragrance and face image. Furthermore, we aimed to determine whether a pleasant fragrance, a commercially available body wash, would have a positive impact on subjective ratings of facial attractiveness of self and other images in the form of attractiveness, confidence, glamorousness and femininity. Given the paucity of research investigating cross modal influence of fragrance on same-sex attractiveness ratings, we were particularly interested in women rating other women. Based on prior literature, it was hypothesised that cross-modal face/fragrance effects for self and other faces in the presence of the pleasant fragrance would modulate mid and late latency ERP components involved in affective processing and cognitive evaluation during face perception.

2.1 Methods

The present study explored how a pleasant fragrance, compared to clean air, affects the electrophysiological activity of the cortex, measured using electroencephalography (EEG), during observation of self- or other-face images. The study was conducted in the EEG Brain and Behaviour laboratories of the University of Liverpool. EEG activity was recorded using a 128-channel Geodesics (EGI, Oregon, USA) system designed for research purposes only.

2.1.1 Participants

22 healthy female participants aged 19 – 30 years (mean ± standard deviation: 25.86 ± 2.80) took part in the current experiment once written informed consent was given in accordance with the Declaration of Helsinki. The study was approved by the University of Liverpool Health and Life Sciences Research Ethics Committee (Psychology, Health and Society - 5688). All participants were free from neurological or olfactory disorders. Data from 3 participants were excluded from behavioural analysis, as they were identified as significant outliers on self-report ratings of visual stimuli (>±3 SD from mean), with a response pattern indicative of systematic responding. Data from 1 participant was excluded from EEG analysis due to excessive movement related artefacts in the EEG data. Hence, behavioural data from 19 participants, and EEG data from 21 participants were retained in the final analysis.

Females aged 18 – 30 years were eligible for inclusion. All participants were initially screened prior to beginning the experiment using a validated procedure known as the 'Sniffin' Sticks' test (Burghart Messtechnik GmbH, Holm, Germany; [34]). The test involved presenting 12 fragrance pens approximately 3 cm beneath a participant's nostrils. Participants were asked to identify each of the 12 test fragrances from a selection of 4 labels for each. Nine correct detections (out of 12 probes) were required to confirm normal sense of smell. All participants identified 9+ fragrances correctly and none were excluded from participation based on the 'Sniffin' Sticks' test outcome. Participants who self-reported neurological disorders such as epilepsy, olfactory disorders such as hyposmia or anosmia, or breathing disorders such as asthma were also excluded. Due to potential interference with electrodes, and to match the make-up free face stimuli selected from the database, participants were asked to avoid wearing makeup on the day when they attended to be photographed. They were also instructed not to smoke, eat, drink or chew gum 2 hours prior to the experiment, to avoid washing their hair the night before, or on the day of testing, and to avoid use of fragranced products such as perfume or deodorant on the day. Participants were reimbursed £30 for their time and travel expenses.

2.2.1 Design

The current study employed a within-subjects design to observe differences in behavioural and electrophysiological measures in two fragrance conditions (pleasant fragrance VS clean air) whilst viewing faces (self or other) displaying neutral emotional expressions and rating their attractiveness, femininity, glamorousness and confidence using visual analogue scales.

2.3.1 Visual and olfactory stimuli

In this experiment 12 face images of female actors, including a mixture of races and ethnicities, were obtained from the Chicago Face Database Set of Facial Expressions [35]. All actors wore grey t-shirts and their faces displayed neutral expressions, with their head and shoulders squared to the camera. All images were in colour, sized at 1086 x 724 pixels with luminance and contrast standardised and a white background. These images will be henceforth referred to as 'other-images'. Images were selected to be representative of the participant sample. While participant ethnicity was not measured or reported in the present study, we anticipated a diverse sample, and database images were selected in line with this. Database image and study participants were matched for age based on study inclusion criteria (age 18 – 30). As photographs of participants were taken on the day of the experiment and immediately loaded on to the experimental task, it was not possible to match images on dimensions of attractiveness, femininity, confidence and glamorousness.

For the self-photographs, 6 photographs of participants own faces were obtained, Participants were made aware in the participant information sheet that their faces would be photographed as part of the experiment. Participants had their photograph taken using a Nikon D3500 camera with a plain white background with studio grade LED lighting. In order to match other-images, they wore a plain grey t-shirt over their clothes with their shoulders squared to the camera and neutral facial expressions. Six photographs of each participant were taken by a researcher with participants' heads facing six different pre-marked angles (head turned approximately 90°, 45° and 22.5° to the left, and then 22.5°, 45° and 90° to the right) to create six 'self-image' stimuli. The decision to include 6 angles in the 'self' condition aimed to reduce repetition suppression which can negatively impact neural ERP responses [4].

Self-image selection was chosen by the experimenters; participants were not shown their photographs prior to completion of the experimental task, or offered opportunity to select their preferred images. Images were re-sized to 1086 x 724 pixels and matched for brightness to the other-images using Corel Photo Paint 2019. These will henceforth be referred to as 'self-images'.

Fragrance or clean air was administered through two tubes sitting approximately 2 centimetres away from the nostrils, using a custom-built, computer-controlled 8-channel olfactometer (Dancer Design Ltd., UK). Fragrance pulses were embedded within a constant flow of clean air, to avoid a sudden pulse of air flow when the fragrance was delivered [36]. Airflow was kept constant at 2.25 l/min in line with previous studies [12,14,37].

The experiment had two fragrance conditions; either ‘fragrance present’ or ‘clean air’ control. The pleasant fragrance stimulus was the commercially available LUX Magical Orchid body wash. This is a floral fragrance typically marketed at women and, as such, was selected as gender congruent and appropriate for addressing our study aims of exploring women’s perceived attractiveness of both themselves and other women. The body wash was presented undiluted via the olfactometer, which results in a perception that is highly similar to smelling the product from the bottle. The odourless inert compound, propylene Glycol (1,2-Propanediol 99%, Sigma-Aldrich Ltd., UK) was used for the clean air control and constant flow in interstimulus intervals. The olfactory stimulation procedure was modelled on previous studies [12]. The body wash was supplied by Unilever. The images and triggering of fragrance valves were controlled using Psychopy 20201.1.0 [38]. In between experimental blocks, an extractor fan was used to filter the environmental air and reduce exposure to residual fragrance in the Faraday cage.

2.4.1 EEG recordings

EEG was recorded continuously over the whole scalp using a 128-channel Geodesics EGI System (Electrical Geodesics, Inc., Eugene, Oregon, USA) with a sponge-based Geodesic Sensor Net. The scalp sensors were placed according to the anatomical landmarks of the head; the pre-auricular points, the nasion and the inion. Electrode-to-skin impedances were kept below 10 kΩ and at equal levels across all electrodes. The recording band-pass filter was 0.01−1000 Hz, and the sampling rate was 1000 Hz. Electrode Cz was used as the reference electrode.

2.5.1 Procedure

Upon entering the Brain and Behaviour Laboratory at The University of Liverpool, informed consent was obtained, and participants were screened to ensure they did not have any allergies, asthma, or olfactory issues. Participants then entered a professional style photo booth (Havox® HPB 200 Photo Booth) and had pictures taken featuring face, down to slightly below level of shoulders using a Nikon D3500 camera. Whilst one experimenter was editing the images and matching them for brightness and size to the ‘other-image’ stimuli, the participant took part in the olfactory screen using the Sniffin’ Sticks test. Following successful completion of the olfactory screen, the EEG cap was applied. After application of the EEG cap, participants were led into in a dimly lit, sound attenuated room and sat facing a 19-inch LCD monitor (60 Hz refresh rate) placed 0.7 m in front of them. Once EEG signal was checked, the olfactometer head piece was fitted, and task instructions were given to participants.

Before participants took part in the experimental task, baseline passive viewing EEG was measured (not reported) and a short task prior to the main experimental task was utilised to gain mean ratings of fragrance pleasantness and intensity for both the pleasant fragrance and the clean air. Participants were asked to rate the smell intensity from ‘0-not intense at all’ to ‘100-very intense’ and pleasantness from ‘0-neutral’ to ‘100-extremely pleasant’.

The experimental task consisted of three blocks of 72 trials (216 trials in total). Each trial consisted of 6, 1 second, face presentations (2 “self-images” and 4 “other-images”) displayed in a pseudorandomised, counterbalanced order, with a 1-second gap between each face presentation (i.e., each stream of images in a trial lasts 12 seconds; see Figure 1 for a schematic illustration of a single trial). These 6 images shown in each stream were utilised for subsequent analysis of neural responses to self- and other – faces in each fragrance condition. The decision to nest multiple face images within a short fragrance exposure was taken to reduce impact of desensitisation which leads to reduced impact of fragrance stimuli on visual processing [39]. This stream of images was followed by a 2 second gap, after which one of the faces from the stream was selected to be a target image and was presented again for 1 second. Immediately after presentation, participants were prompted to rate this target image on two of a possible four rating scales; either attractiveness, confidence, femininity or glamorousness, using on-screen visual analogue scales. For example, participants rated attractiveness (from 0-extremely unattractive to 100-extremely attractive) and confidence (0-extremely unconfident to 100-extremely confident). During the exposure to the entire photo stream and final face presentation a 15 second pulse of either the pleasant fragrance or clean air.

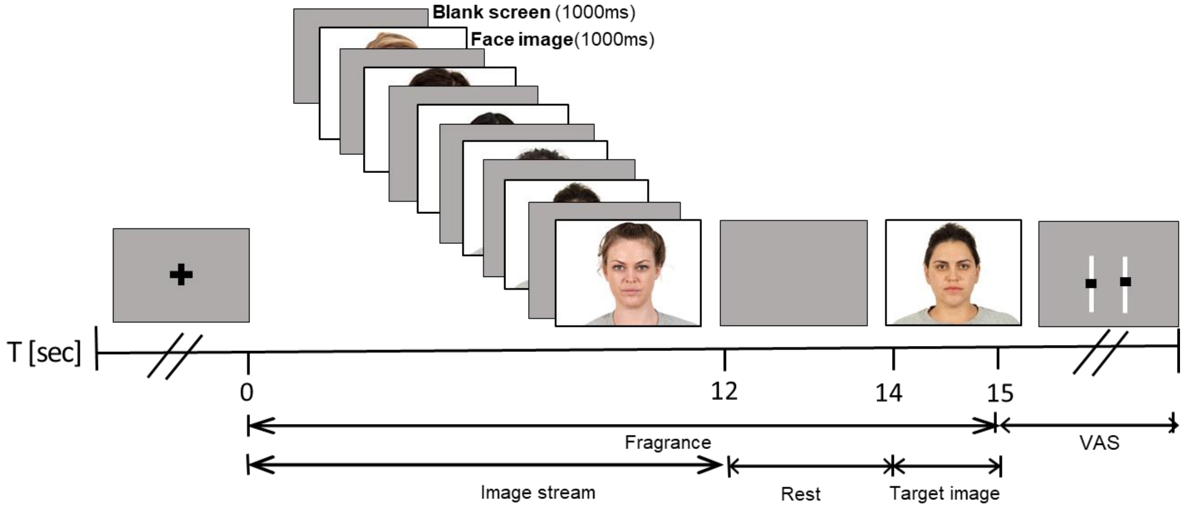

Figure 1. A flow chart depicting a single trial of the experiment. Each trial consisted of 6, 1 second, face presentations, with a 1-second gap between each face presentation (i.e., each stream lasts 12 seconds). This was followed by a 2 second gap, after which one of the faces was presented again for 1 second and participants were prompted to rate this target image on two of a possible four rating scales; either attractiveness, confidence, femininity or glamorousness, using on-screen visual analogue scales.

At the start of each trial, participants viewed a black fixation cross on a grey background. Participants were instructed to relax and breathe normally during this time. A pulse of fragrance (pleasant fragrance or clean air) was triggered at the onset of a stream of six face images (2 self-images, 4 other-images). After the sixth image, there was a 2 second rest, and then one of the images from the stream was presented again for 1 second. Participants were instructed to attend to the full image stream, but only rate the final image presented in each stream, after the brief rest period. Immediately after image offset, two consecutive visual-analogue scales prompted participants to rate the face in the target photograph on two of four measures (attractiveness, confidence, femininity and glamorousness), 15 seconds after fragrance onset. Utilising 2, out of 4 available, rating scales for each trial increased task engagement and prevented systematic responding. Once participants had completed these ratings, there was a 16 second washout period of clean air delivery before the next trial began.

In each block, trials were pseudorandomised so that each image (6 self-images, 12 other-images) were rated once per fragrance condition on each of the four self-report ratings. Both fragrances were presented in a pseudorandom order across each block; the same fragrance was presented no more than twice consecutively. In total, the full experimental session lasted approximately 90 minutes including experimental set up and the experimental task.

2.6.1 Analysis

2.6.1.1 Behavioural analysis

T-tests revealed intensity ratings were significantly higher for the fragrance condition (M= 65.67, SD = 15.60) than a clean air control (M = 9.70, SD = 11.73), $t(21) = 13.58$, $p < .001$, Cohen's d = 0.29. Similarly, the fragrance condition (M = 52.56, SD = 17.85) was rated as significantly more pleasant than a clean air control (M = 6.20, SD = 8.55), $t(21) = 12.38$, $p < .001$, Cohen's d = 0.24

Significant outliers (n=3) on self-report ratings of visual stimuli (>±3 SD from mean), were removed prior to analysis. As data following outlier removal was normally distributed, transformations were deemed unnecessary and not applied. This is in line with suggestions by Osborne [40] who cautions that transformations can complicate interpretation of data. Behavioural data was analysed using 2 × 2 within-subjects ANOVA to observe whether there were statistically significant differences in evaluation of faces (self- or other-images) in the presence of different fragrances (pleasant fragrance or clean air). Four separate ANOVAs were performed for each rating type; attractiveness, confidence, femininity and glamorousness. Significant main effects were investigated using pairwise comparisons using Bonferroni correction for multiple comparisons. Behavioural data was analysed using IBM SPSS Statistics for Windows, version 27 (IBM Corp., Armonk, N.Y., USA).

2.6.2.1 ERP analysis

EEG recordings were pre-processed in BESA v. 6.1 software (MEGIS GmbH, Germany). Standard pre-processing procedures were implemented; data was down-sampled to 256 Hz, re-referenced to a common average using the common averaging method [41], and band-pass filtered (0.1 – 45 Hz). Eyeblinks were removed using principal component analysis and electrode channels containing large artefacts were interpolated. Trials contaminated by movement artefacts were identified through visual inspection and affected trials manually marked for exclusion from analysis. Stimulus onset was defined as the onset of each image present in the passive viewing stream, ERPs were time locked to the onset of each image in the stream. Trials were epoched -200 to 800 ms relative to image onset, and were baseline corrected -200 to 0 ms. This allowed us to analyse event related potentials (ERPs), which are averaged electrical brain responses gathered via EEG directly resulting from a particular event, which in this case, was the presence of an image of face.

After pre-processing, statistical analysis was performed in FieldTrip [42] (Donders Institute for Brain, Cognition and Behaviour, Radboud University, the Netherlands. See http://fieldtriptoolbox.org). To minimize the risk of false positive errors due to the large number of statistical tests, a hypothesis-independent permutation analysis (1000 permutations), implemented in the statcond.m program in the EEGLab package [43] was used to perform a 2 × 2 ANOVA analysis at every electrode across every time point in each epoch (256 time points covering -200 ms to +800 ms relative to stimulus onset). This was used to identify clusters of electrodes demonstrating significant main effects of fragrance or face image, or interactions between these conditions separately [44]. The cluster-based method provides a data-driven approach to assess effects of fragrance and face type on electrophysiological activity across all electrodes without making a priori assumptions regarding specific ERP components or scalp locations, while also controlling for multiple comparisons with no loss in statistical power.

In order to identify significant clusters and latencies in a more objective way, for each cluster in the solution, 95% confidence intervals for the mean IC cluster activity were calculated across the whole epoch; -200 to 800 ms. Only clusters in which the confidence intervals deviated from baseline (confirmed with one-way ANOVA analysis of grand average ERP data) were subjected to further statistical analysis. Data from electrode clusters and time periods which demonstrated effects in the multivariate analysis were exported for consideration of impact of the pleasant fragrance (versus clean air) on ERPs to self- and other-images. A statistical critical value threshold of $p < 0.05$ was maintained throughout.

Correlational analyses were performed to understand the meaning of differential EEG effects for Self-Other conditions in clean, relative to the pleasant fragrance, conditions. Variables were computed by averaging self and other data across fragrance conditions and then subtracting the pleasant fragrance data from clean air. This method allowed exploration of whether greater change in brain activity correlated with greater change in behavioural ratings, and reduced the number of comparisons made. After removal of an outlier (> 3 SDs outside of the mean voltage in the ERP components), a series of Spearman’s rho correlations were performed for each variable of interest.

Finally, correlational analyses were also performed to investigate whether individual ratings of perceived fragrance pleasantness and intensity related to significant behavioural or EEG outcomes. Differential values for each behavioural or electrophysiological measure, which corresponded to significant results in ANOVA analyses, were correlated with individual ratings of odour pleasantness and intensity. For example, the main effect of odour presence on attractiveness was calculated by summing attractiveness ratings for self- and other-images in the pleasant odour condition, and subtracting the sum of ratings for same conditions in presence of clean air. This value was correlated with individual ratings of perceived odour pleasantness and intensity.

3.1 Results

3.1.1 Face ratings during fragrance presentation

Figure 2 shows line graphs of the mean subjective ratings of attractiveness, confidence, glamorousness and femininity for self- and other-images when participants smelled the pleasant fragrance or clean air.

To examine the statistical significance, a series of 2 × 2 repeated measures analysis ANOVAs were conducted individually for attractiveness, confidence, femininity and glamorousness to consider the main effect of fragrance on each rating type, whether the evaluation of self-versus other-images differed, and whether there was any interaction effect between fragrance and face type (see 1).

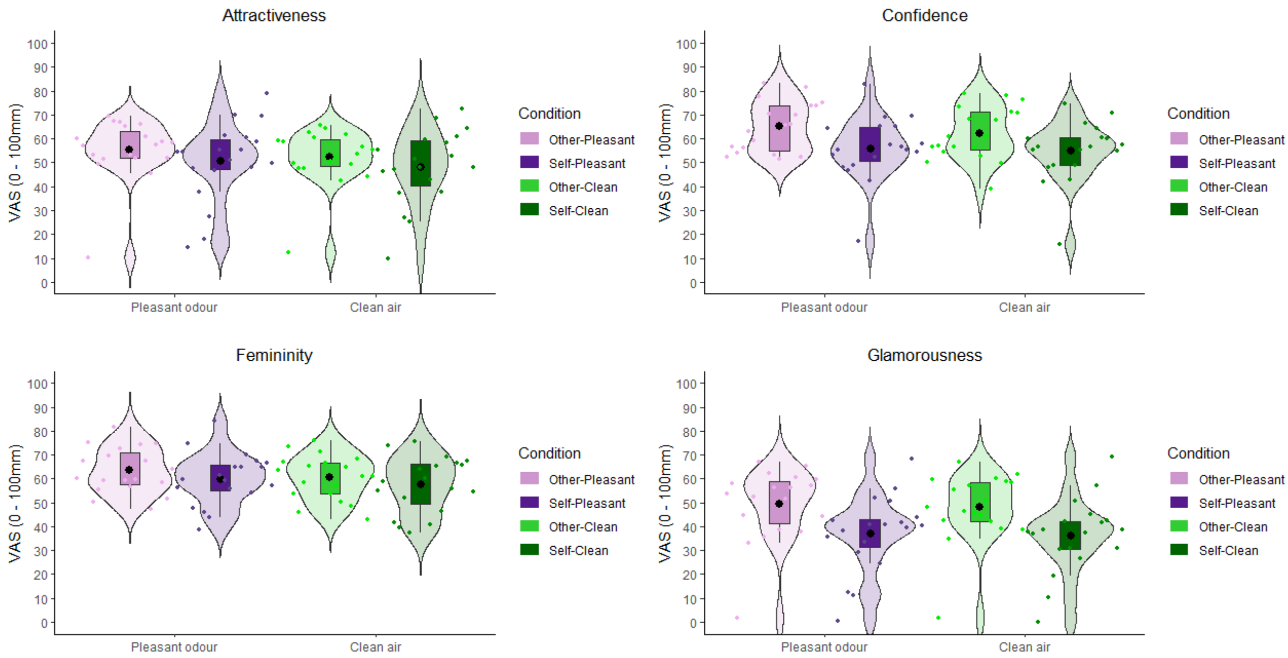

Figure 2. Violin plots depicting distributions of subjective responses for ratings of attractiveness, confidence, femininity and glamorousness in pleasant odour conditions for self (dark purple) and other (light purple) images, and clean air condition with self (dark green) and other (light green) images. The coloured individual dots show data points from each participant, the bold black dot indicates the mean. The boxplots indicate the interquartile range (IQR) between the 25th and 75th percentile, and the whiskers represent 1.5 times IQR.

The ANOVAs revealed a significant main effect of fragrance across three of the four rating scales ($p < 0.05$) indicating more positive ratings for faces in presence of the pleasant fragrance compared to clean air. This was identified in attractiveness ($F(1, 18) = 5.204$, $p = .035$, $\eta p^2 = .22$) confidence ($F(1, 18) = 6.223$, $p = 0.022$, $\eta p^2 = .25$) and femininity ratings ($F(1, 18) = 4.479$, $p = .049$,$\eta p^2 = .20$). There was no effect of fragrance on glamorousness ratings ($p > 0.05$) (See Figure 1). There was a main effect of ‘self-other’ for ratings of confidence $F(1, 18) = 4.881$, $p = .04$, $\eta p^2 = .21$) and glamourous $F(1, 18) = 15.092$, $p = 0.001$, $\eta p^2 = .46$). This indicates that participants rated other-images significantly higher than themselves on these rating scales. A similar non-significant trend ($p < .1$) was evident in attractiveness and femininity ratings, i.e., participants consistently rate themselves more negatively than others. However, there were no significant interactions between fragrance and self-other effects. This indicates that any perceived effect of fragrance is consistent across self- and other-image ratings.

3.2.1 ERP components

Figure 3 demonstrates ERP components elicited in response to all faces across all trials and participants, regardless of fragrance condition, in the form of a grand average butterfly plot. The grand average butterfly plot represents an overlay of ERP waveforms from every electrode, collapsed across all 4 conditions. This data was visually inspected to identify distinct components which are correspond to peaks in global field power. Peak times representing maximal voltage in each recognisable distinct component were extracted via manual inspection. ERPs are characterized by their topography (i.e., where the activation occurs on the scalp) and their latency (i.e., when the effect occurs), which guide the interpretation of results. The first ERP component peaked at 98 ms, which is within the latency of the N1 Visual Evoked Potential (VEP) component; a component that peaks over central regions around 100 ms post-stimulus and is related to early visual processing of stimuli. A second negative ERP can be observed peaking at 200 ms post stimulus, which could be the N170, a component that is widely elicited in response to processing facial stimuli [45]. The next component showed a smaller negative peak at 280 ms which could also reflect the N2 component associated with early visual attention and evaluation [46]. Another peak is present at 380 ms, the P300 component, which is involved in conscious attention to self-relevant stimuli [47]. Finally, a peak at 580 ms falls in the period of the LPP, a component related to higher-level processing of emotions

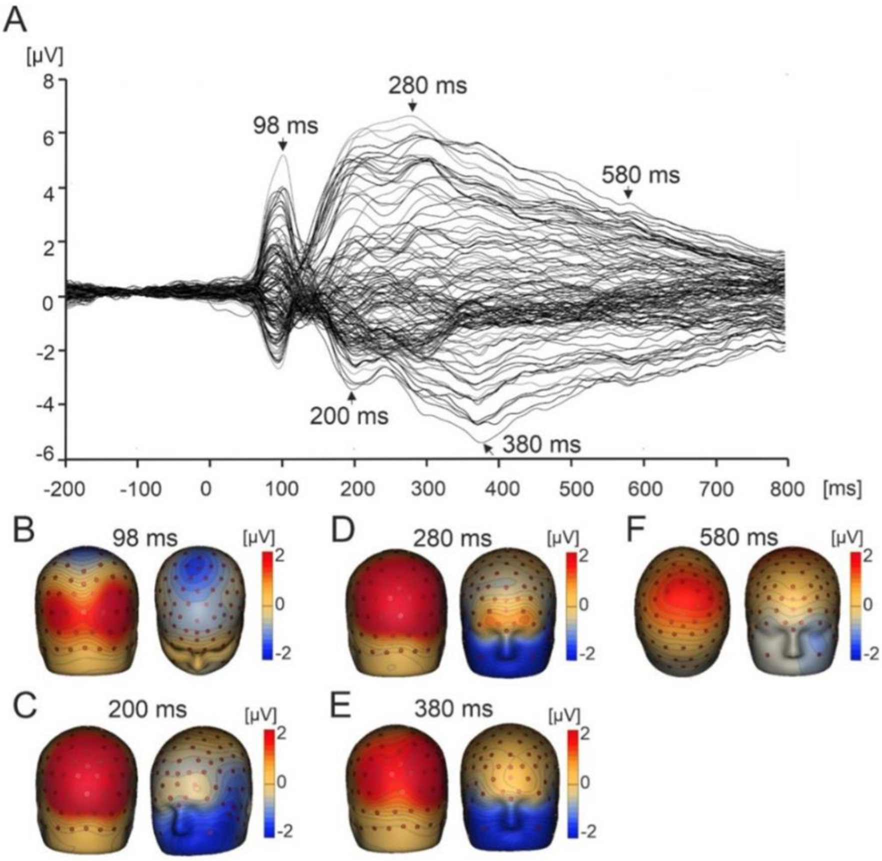

Figure 3. Butterfly plot of grand average waveforms to faces and corresponding scalp topographies for peak latencies. (A) Butterfly plot representing data for all electrodes across the whole period of the ERP averaged across all faces and fragrance conditions . Peak latencies of distinct ERP components (N1, N2, P3, LPP) are highlighted with arrows (98 ms, 200 ms, 280 ms, 380 ms and 580 ms). (B) Latency component 98 ms (N1). (C) Latency component 200 ms (N170). (D) Latency component 280 ms (N2). (E) Latency component 380 ms (P3). (F) Latency component 580 ms (LPP).

3.3.1 Effect of fragrances on ERPs

A permutation analysis was used to perform a 2 × 2 ANOVA analysis at every electrode across every time point in each epoch (256 time points covering -200 ms to +800 ms relative to stimulus onset) to assess whether fragrance altered the neurophysiological processing of faces reflected in cortical ERP clusters. The ANOVA revealed four scalp-time clusters that showed significant effects of fragrance within the N1, N2, LPP and P3 components. Significant main effects of fragrance at the N1 (fig 4), N2 (fig 5) and LPP (fig 6), and fragrance – image type interactions at the N2 (fig 7) and P3 (fig 8) components are discussed in detail in the following sections. Amplitude data was extracted from each of the scalp-time clusters and further one-way ANOVAs were computed on the data using SPSS statistics (IBM Corp., Armonk, N.Y., USA).

3.3.1.1 N1

Figure 4 shows the first significant time cluster covering the time period 75-115 ms, which illustrates a main effect of fragrance type (pleasant fragrance versus clean air) on the ERP responses to faces. This falls within the latency of the N1 ERP component, which typically peaks around 100 ms with frontal negativity and occipital positivity. The corresponding topographic maps from each fragrance condition for each significant cluster (figure 4A) are shown with grand averaged waveforms ERPs across all participants highlighting the significant latency interval around the peak, and bar graphs showing the mean EEG scalp-amplitude (μV) for each fragrance and face condition (Figure 4C).

A 2 (self- vs other-images) × 2 (fragrance: pleasant fragrance vs clean air) repeated measures ANOVA revealed a statistically significant main effect of fragrance ($F(1, 20) = 10.799$, $p = .004$, $\eta p^2 = .35$). This indicates that the negative N1 ERP brain component in a cluster of 7 central-frontal electrodes was enhanced during processing of faces in the presence of the pleasant fragrance compared to clean air conditions.

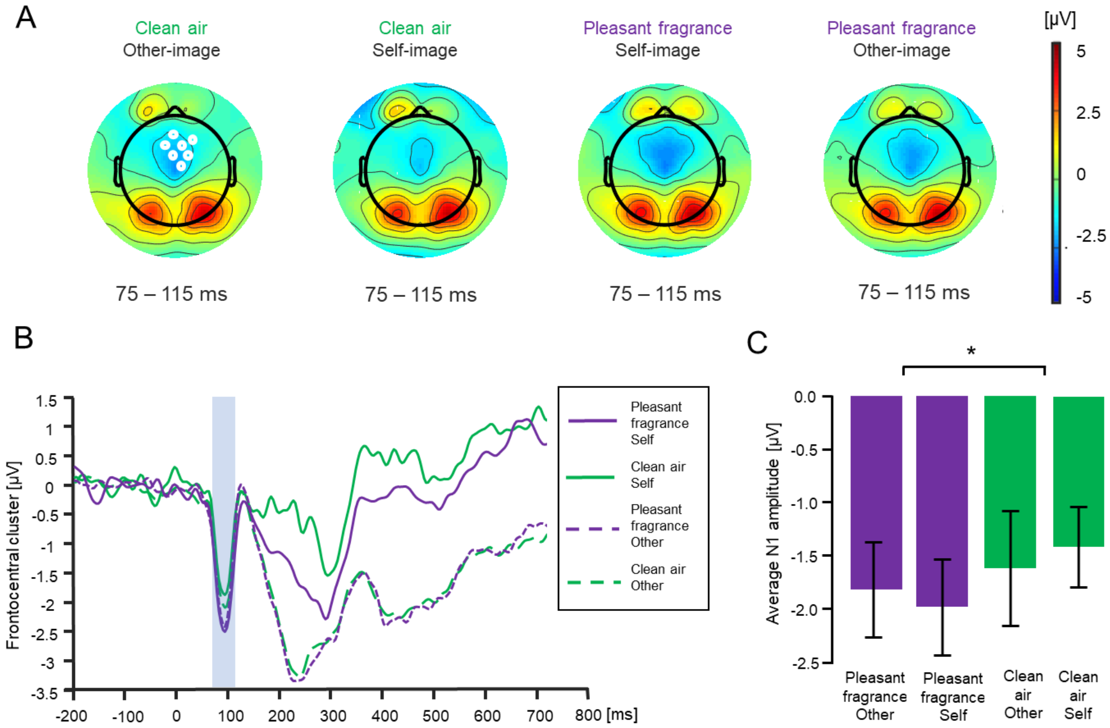

Figure 4. Impact of the pleasant fragrance on Facial ERPs at – N1 Component. (A) Whole head topographies maps for grand averaged N1 (75 – 115ms) with differences in negative activation within a middle frontal cluster of electrodes (E4, E6, E11, E12, E112 and E118 electrodes) when viewing facial images (self- and other-images) in the presence of the pleasant fragrance versus clean air. B) Grand Average ERP across a middle frontal cluster of electrodes between 75-115 ms. C) Bar chart of the mean N1 amplitudes of ERP waveform depicted above over epoch 75 – 115 ms from the same cluster of electrodes. The error bars shows the standard error.

3.3.2.1 N2

Figure **5** shows the second significant time cluster covering the time period 170 –290 ms which also illustrates a main effect of fragrance type (pleasant fragrance versus clean air) on the ERP responses to faces. The ERP falls within the latency of the N2 ERP component, N2 is a negative peak 200 – 300 ms post-stimulus over anterior central regions. The corresponding topographic maps from each fragrance condition for each significant cluster (figure 5A) are shown with grand averaged waveforms ERPs across all participants highlighting the significant latency interval around the peak, and bar graphs showing the mean EEG scalp-amplitude (μV) for each fragrance and face condition (Figure5C).

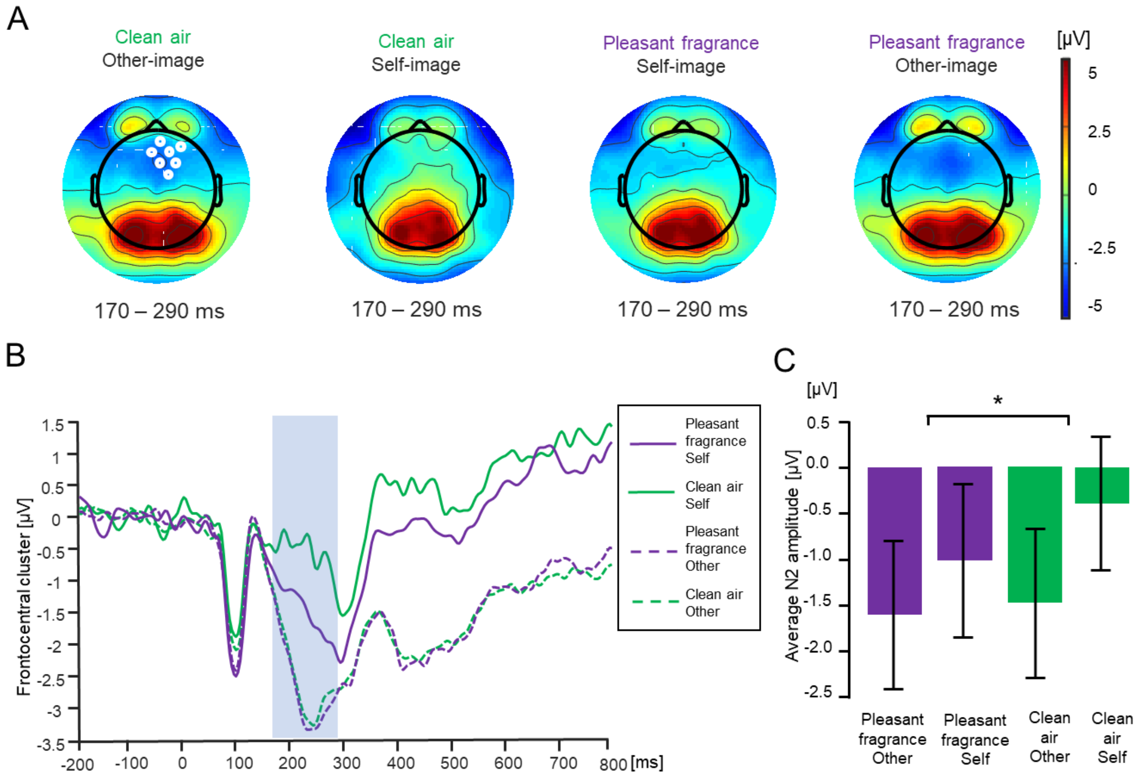

Figure 5. Impact of pleasant fragrance on Facial ERPs – N2 Component. (A) Whole head topographic maps for grand averaged N2 (170 – 290ms) with differences in negative activation within a frontal-central cluster of electrodes (E4, E5, E6, E11, E12, E112, E118) when viewing facial images (self- and other-images) in the presence of pleasant fragrance versus clean air.(B) Grand average ERP waveform within a frontal-central cluster of electrodes across all subjects comparing other-images in the presence of pleasant fragrance (solid purple line) or a clean air control (solid green line) and self-images in the presence of pleasant fragrance (dashed purple line) or clean air (dashed green line). Epoch of interest 170 – 290 ms post feedback-onset highlighted in grey (C) Bar chart of mean N2 amplitude of ERPs over epoch 170 – 290ms from a cluster of fronto-central electrodes. The error bars show the standard error.

A 2 (self- vs other-images) X 2 (fragrance: pleasant fragrance vs clean air) repeated measures ANOVA revealed a statistically significant main effect of fragrance $F(1, 20) = 10.165$, $p = .005$, $\eta_p^2 = .34$ (See Figure 5), in a cluster of 7 central-frontal electrodes which demonstrated enhanced N2 ERP negativity during processing of faces in the pleasant fragrance, relative to clean air, condition.

3.3.3.1 LPP

Figure 6 shows the third significant time cluster covering the time period 425–580 ms which also illustrates a main effect of fragrance type (pleasant fragrance versus clean air) on the ERP responses to faces. The ERP falls within the latency of the LPP ERP component, which is a positive waveform occurring in occipital/parietal electrodes, typically beginning around 400 ms. The corresponding topographic maps from each fragrance condition for each significant cluster show positive activation in a right parietal cluster (Figure 6A) and are shown with grand averaged waveforms ERPs across all participants highlighting the significant latency interval around the peak, and bar graphs showing the mean EEG scalp-amplitude (μV) for each fragrance and face condition (Figure 6C).

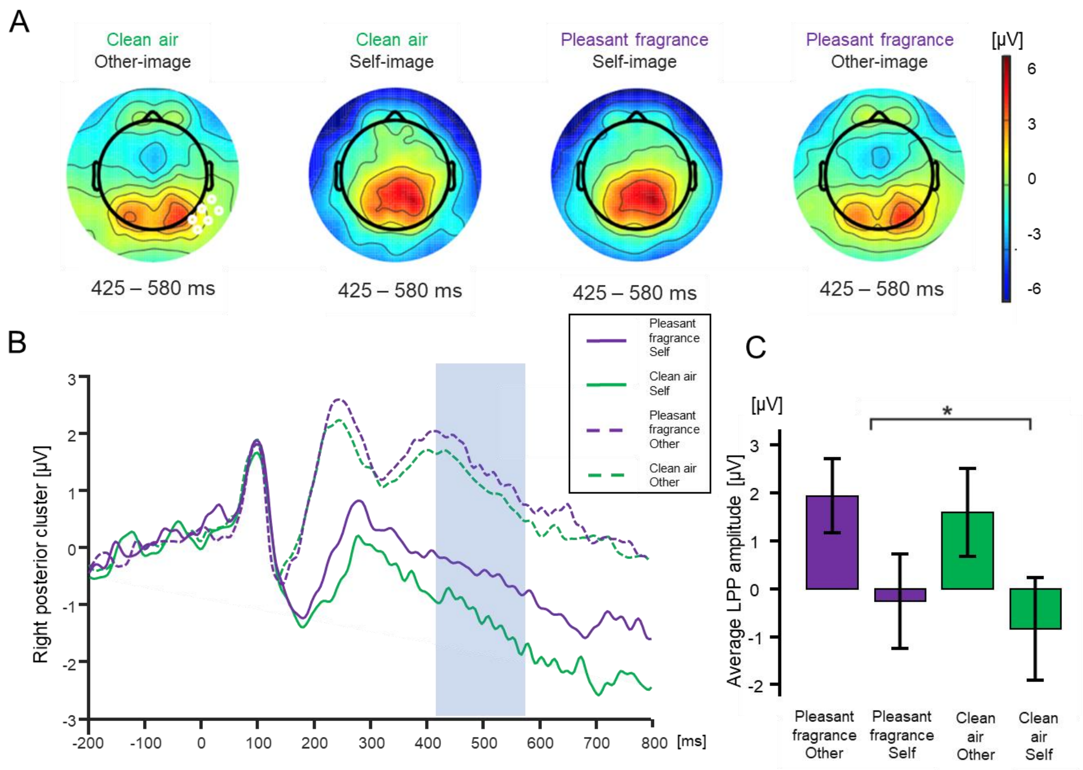

Figure 6. Impact of the pleasant fragrance on Facial ERPs – LPP Component. (A) Whole head topographic maps for grand averaged LPP (425 – 580 ms) displaying differences in positive activation within a cluster of right posterior electrodes (E95, E96, E100, E101, E107, E108). (B) Grand Average ERP waveforms comparing other-images in the presence of pleasant fragrance (solid purple line) or a clean air control (solid green line) and self-images in the presence of pleasant fragrance (dashed purple line) or clean air (dashed green line) across the right posterior electrode cluster for all participants between 425– 580 ms (highlighted in grey), (C) Bar chart of the mean electrical amplitudes of ERPs depicted above over epoch 425 – 580 ms (N2) from the same cluster of electrodes. Error bars show the standard error.

A 2 (self- vs other-images) × 2 (fragrance: pleasant fragrance vs clean air) repeated measures ANOVA revealed a statistically significant main effect of fragrance, with enhanced positivity during LPP ERP component in a cluster of 6 right occipital-parietal electrodes in the pleasant fragrance condition compared to clean air regardless of face type $F(1, 20) = 11.534$, $p = .003$, $\eta_p^2 = .37$ (See Figure 5C).

3.4.1 Interactions between fragrance type and self-other image on ERPs

3.4.1.1 N2

In the second time cluster covering the time period 170-290 ms, in the latency of the N2 component, an interaction between fragrance and face condition was observed. Figure 7A shows the topographic maps for each fragrance and face condition for a frontal negative cluster of electrodes (E4, E5, E6, E11, E12, E112, E118), demonstrating enhanced frontal negativity for other images regardless of fragrance condition. Figure 7B displays grand averaged N2 ERP waveforms across all participants highlighting the significant latency interval around the peak, with more negative N2 waveforms for other images regardless of fragrance condition.

A 2 (self- vs other-images) × 2 (fragrance: pleasant fragrance vs clean air) repeated measures ANOVA revealed a statistically significant interaction between fragrance and face-image in a cluster of 6 central electrodes, with self-images produced more negative N2 waveforms in the presence of the pleasant fragrance compared to clean air $F(1, 20) = 15.623$, $p = .001$, $\eta_p^2 = .439$. Figure 7C shows the interaction between fragrance type and face type, with other images producing more negative N2 amplitude regardless of fragrance type, however, the presence of the pleasant fragrance produced more negative N2 amplitudes in the self-image condition, compared to clean air.

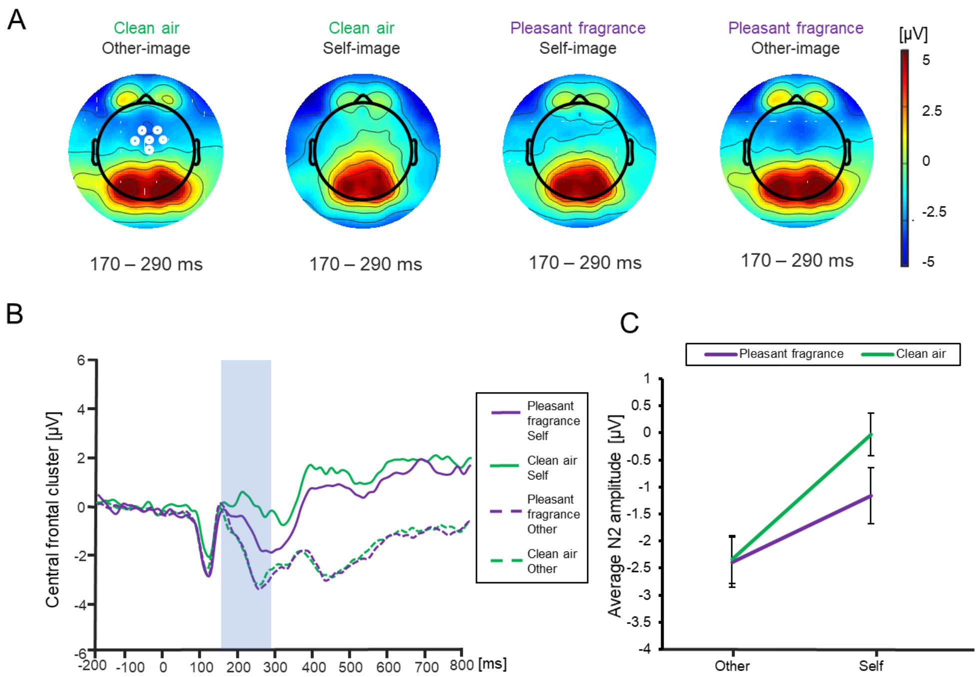

Figure 7. Interactions between fragrance and self-other effects – N2. (A) whole head topographic maps displaying grand average activation between 170 – 290 ms for each fragrance and image condition type in central frontal cluster of electrodes (E6, E7, E13, E106, E112, Cz). (B) Grand average N2 ERP waveform displaying other-images in the presence of the pleasant fragrance (solid purple) or a clean air control (solid green) and self-images in the presence of the pleasant fragrance (dashed purple) or clean air (dashed green). Significant interval (170 – 290 ms) highlighted in grey. (C) Line graph of mean N2 amplitude of ERPs between 170 – 290 ms in central frontal cluster of electrodes.

3.4.2.1 P3

Figure **8** highlights that an interaction effect was also observed in an additional time cluster covering the time period 315 – 400 ms, in the latency of the P300 component. This cluster did not initially show any main effect of fragrance on face processing within this time period in this frontocentral cluster of electrodes. Figure 8A shows the topographic maps for each fragrance and face condition for a frontal central of electrodes (E4, E5, E6, E11, E12, E112, E118), demonstrating enhanced frontal positive activation for self-images, regardless of fragrance condition. Figure 8B displays grand averaged P300 ERP waveforms across all participants highlighting the significant latency interval around the peak, with more positive P300 waveforms for self faces regardless of fragrance condition.

The ANOVA revealed that the interaction between fragrance and self-other effects in the central P3 (315 – 400 ms) was significant, $F(1, 20) = 20.995$, $p < .001$, $\eta p^2 = .512$, with the pleasant fragrance significantly reducing the augmentation of P3 amplitude seen for self-image viewing condition compared to other faces. Figure 8C Shows the interaction between fragrance type and face type, with self-images producing enhanced P300 positive amplitude, however the augmented P300 amplitude seen during self-images appears to be reduced in the pleasant fragrance condition.

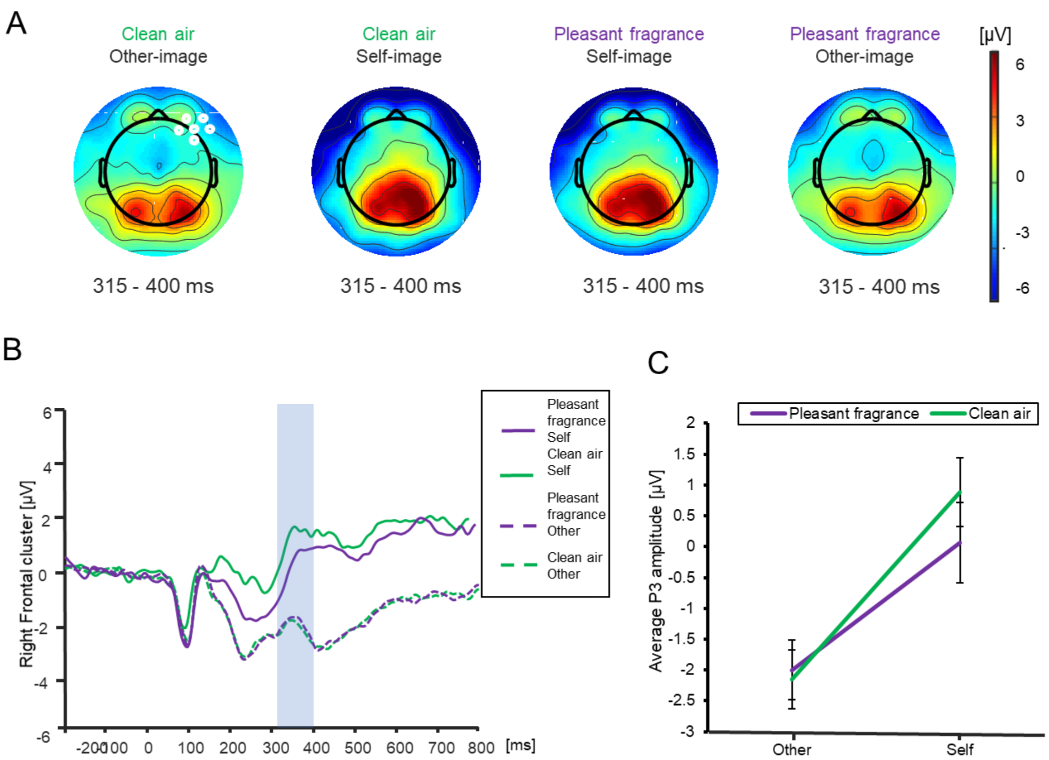

Figure 8. Interactions between fragrance and self-other effects – P3. (A) Whole head topographic maps displaying differences in grand average P3 ERP activation between 315 – 400 ms in a fronto-central electrode cluster. (B) Grand average ERP waveform across all subjects comparing P3 activity to own face images in the presence of pleasant fragrance (solid purple line) or a clean air control (solid green line) and other-face images in the presence of pleasant fragrance (dashed purple line) or clean air (dashed green line). Epoch of interest 315 – 400 ms post feedback-onset highlighted in grey. (C) Line graph displaying mean amplitude of ERPs over epoch 315 – 400 ms from frontocentral electrodes cluster, showing reduced P3 amplitude for other-images across both fragrance conditions, and enhanced P3 positivity for self-images, which was reduced when the pleasant fragrance was present).

3.5.1 Correlations between behavioural ratings and ERP components

Table 1 depicts the Spearman's rho correlations between fragrance and image interactions for the four behavioural ratings (attractiveness, confidence, femininity and glamorousness), two face image conditions (own-face other-face), and each significant ERP component with a main effect of fragrance (N1, N2, LPP) and two interaction effects (N2, P3).

Statistically significant positive correlations were found between attractiveness and femininity ratings, femininity and confidence, N1 and N2 interaction, N2 and N2 interaction, P3a interaction and attractiveness, P3 interaction and N2, and P3 interaction and N2.

Table 1

	1.	**2.**	**3.**	**4.**	**5.**	**6.**	**7.**	**8.**
1.Attractiveness	1.000	-	-	-	-	-	-	-
2. Confidence	.326	1.000	-	-	-	-	-	-
3. Femininity	.661*	.478*	1.000	-	-	-	-	-
4. Glamorousness	.404	-.026	-.018	1.000	-	-	-	-
5. N1	.225	-.199	.047	.348	1.000	-	-	-
6. N2	.135	-.010	.044	.040	.394	1.000	-	-
7. LPP	.012	.306	.032	.008	.057	-.168	1.000	-
8. N2 Interaction	.206	-.011	.216	.046	.535*	.803*	-.140	1.000
9. P3 Interaction	**.505***	-.055	.389	.202	.352	.777*	-.335	.843*

Table 1 Correlations between fragrance-image interactions for four behavioural ratings (Attractiveness, Confidence, Femininity and Glamorousness) and five ERP components (N1, N2, LPP, N2 interaction and P3 interaction).

We also performed a series of Spearman's Rho correlations to compare individual differential ratings for each behavioural or electrophysiological measures that demonstrated significant results in ANOVA analyses, with subjective ratings of odour pleasantness and intensity. None of the behavioural or EEG outcomes demonstrated any significant relationship with individual ratings of odour pleasantness or intensity.

4.1 Discussion

Results showed that the pleasant fragrance of the commercially available body wash impacted how our participants rated faces of self and others. Self- and other-image faces were subjectively rated as more attractive, confident and feminine in the presence of the pleasant fragrance compared to an odourless control. Effects of the fragrance on electrophysiological processing of faces were evident in four well established ERP components covering early-to-late stages of visual processing; N1, N2, P3 and LPP. Moreover, there was evidence of a cross-modal fragrance-face interaction effect, with the pleasant fragrance particularly modulating ERPs to self-images in mid-latency N2 and P3 components.

4.1.1 Effects of fragrance presence on face perception

The current study findings revealed that when women’s faces (self and other) were presented in conjunction with the pleasant fragrance of the commercially available body wash, the faces were rated as more attractive, confident and feminine than when the same faces were presented alongside an odourless control. This finding is consistent with previous literature [11] which observed that faces paired with a pleasant fragrance resulted in enhanced pleasantness ratings for both the face and the fragrance in a bidirectional manner. The current study revealed that self-images were rated less favourably overall compared to other images, however, the introduction of the pleasant fragrance was associated with reduced negativity of self-image ratings. The global enhancement that the pleasant fragrance had which positively impacted the ratings of faces (both self- and other-images) aligns with previous studies which observed global enhancements in pleasantness of other-face ratings irrespective of facial expression valence [12].

This study is the first to demonstrate the positive effect of a pleasant fragrance in a sample of women rating themselves and other women. The literature on multisensory fragrance/visual perception has shown differences in olfactory processing according to biological sex, with females typically demonstrating superior olfactory abilities [48], and male-female asymmetry in processing emotional olfactory stimulation [49,50]. Therefore, the current study is the first, to our knowledge, to demonstrate that a pleasantly valenced fragrance can not only amplify positive evaluation of attractiveness, femininity and confidence when viewing female faces of other, but can also amplify positive evaluation of these features in images of oneself.

4.2.1 Effects of fragrance-face combinations on electrophysiological responses.

Effects of fragrance were observed during the N1 component of face ERPs. The N1 is an event related brain potential which shows a large negative deflection from baseline approximately 100 ms following the onset of a stimulus [51]. Research into N1 has shown evidence of multisensory integration and perception across fragrance and visual modalities, with fragrance modulating visual N1 and enhancing task performance by providing an olfactory association cue [52]. Furthermore, N1 has shown modulation according to emotional face expressions [53]. In the present study, the N1 ERP to face images was significantly enhanced in the presence of the pleasant fragrance, compared to clean air, in a cluster of centro-frontal electrodes, irrespective of whether participants were viewing own- or other-face images. This suggests that early stages of face-processing were enhanced in the presence of a pleasant fragrance, perhaps indicating that, in the context of a pleasant fragrance, faces receive greater attentional processing. This finding is supported by previous studies which have demonstrated ERP modulation by level of facial attractiveness at early stages of processing [54–57]

It is important to note that, as olfactory stimuli reach the nasal epithelium at a significantly slower rate than visual stimuli reach the retina [58], fragrance was continuously presented across each 15second trial, and was not time-locked to the specific target face being rated for facial attractiveness. Consequently, global effects of the fragrance on mood and arousal would precede most images shown on a trial. Research indicates that valenced odours can induce a generalised mood state which could theoretically influence participants' experience and perception [59] Similarly, odours can induce general arousal, which can facilitate faster processing of affective stimuli such as faces [60]. It is plausible that the effects presented here could be explained by general enhancements of mood and arousal produced by the presence of a pleasant odour. Nonetheless, as fragrance presentation was altered on a trial by trial basis, this seems unlikely, and may be better explained by a cross-modal affective processes. Results are consistent with prior research suggesting greater early attentional processing, evidenced by enhanced N1 activity in response to faces presented in the context of anxiety related chemosensory signals [61]. However, to our knowledge, this is the first time N1 has been implicated in modulation of fragrance-face pairings by pleasant fragrance, extending these findings by demonstrating that a pleasant fragrance can also modulate N1 amplitude in response to neutral faces. Combined with the fact that the presence of a pleasant fragrance was associated with enhanced ratings of facial attractiveness, confidence and femininity, this finding points towards a cross-modal influence of the pleasant fragrance in positively influencing evaluations of self- and other-image faces automatically and preconsciously.

Previous research has demonstrated that congruent cues from multiple modalities can facilitate object recognition speed and accuracy, particularly for fragrances and visual perception, as they have a natural correspondence [62,63]. This interesting finding in N1 suggests that within 100 ms of viewing own- or other-face images, the presence of the pleasant fragrance of the commercially available body wash preconsciously and automatically upregulates the opinion of ourselves and others. What is striking is that this modulation of the N1 is not universal to all pleasant fragrances. A case in point is Cook et al. [12] who failed to find this extremely early modulation of the ERP by another pleasant fragrance (jasmine) in participants viewing images of others from the same database. Whilst the present study only presented one pleasant and one neutral fragrance, it is not possible to determine whether the effects reported are specific to the pleasant fragrance used. Future research is required to elucidate the properties of fragrances that boost N1 to facial images, as compared to fragrances that do not.

In line with prior research [12], an effect of fragrances on face processing was also observed for the N2 component, which has been suggested to index enhanced facial attractiveness [25,27], and has been modulated by fragrance-face interactions [12]. In the current study, activation in the N2 component enhanced by the presence of the pleasant fragrance and the impact of fragrance was also greater for self-images, compared to others. Considering the self-report ratings, which were consistently less positive for self, compared to other-images, the interaction effect observed in N2 modulation, driven by the pleasant fragrance could index a reduction of negative attention to self. Therefore, following on from the automatic enhanced perception in the N1, the pleasant fragrance could continue to positively impact self-perception at an early, more conscious stage of processing. This finding is supported by studies examining ERPs to facial attractiveness which observed enhanced N2 amplitude to more attractive faces [25,27].

In line with our expectations, the multisensory effect of fragrance on face processing was also evident at later stages of processing within the LPP. The LPP is a positive deflection beginning around 400 ms post stimulus in the occipital parietal cortex and is typically associated with the processing of stimuli valence [64–67]. The LPP has also been implicated in the processing of facial attractiveness [27]. Specifically, the current study observed more positive LPP amplitude to both face-image types in the presence of the pleasant fragrance. Modulation of LPP amplitude according to face pleasantness [12] has been supported by prior research, and studies have demonstrated that both negatively and positively valenced fragrances can modulate LPP amplitude and behavioural ratings during face processing [68].

Therefore, modulation of LPP to faces according to fragrance may reflect the complex aspects of evaluation of facial attractiveness, emotional content and stimuli valence which occurs in a top-down fashion, in contrast to bottom-up automatic cognitive processes which occur at earlier stages of processing, such as the N1. As the pleasant fragrance increased ratings of facial attractiveness, confidence and femininity in own and other-face images, this evaluation may reflect conscious appraisal of such features. Taken together, results suggest that the pleasant fragrance of the body wash alters top-down evaluation and engagement with face images and may amplify conscious positive appraisal of self and other faces. Therefore, the pleasant fragrance may upregulate women’s perception of themselves and others, creating a globally more positive perception, reflected in enhanced LPP.

Finally, the current study observed an interaction effect between fragrance presence and face type within the P3 ERP component, a positive potential occurring between 250 – 450 ms in midline electrodes [69]. The P3 is known to be modulated by stimulus valence [69–73] facial attractiveness [28,29], and is an index of self-relevance [74]. The current study findings revealed enhanced positive activation of P3 for self-images compared to other-faces, but this difference was reduced in the presence of the pleasant body wash fragrance. Enhanced P3 amplitude for own-face perception is in line with previous research which has shown enhanced P300 amplitude for own-face images compared to a famous face [31,75–79]. This is because the human brain performs in a specialised manner during processing one’s own face, compared to others, and P3 is associated with processing of salient target stimuli [31]. It is possible that the presence of the pleasant fragrance amplified brain responses to own faces, reflected in the P300. However, the amplified P300 to self-faces was found to be reduced when in the presence of the pleasant fragrance, producing responses similar to the other-face condition The current findings are also supported by the literature on ERP responses to attractive faces, as previous studies have observed modulation of P3 amplitude to attractive faces [28,29] Consequently, the P3 (and earlier N2) interaction effects lead to the possibility that the pleasant fragrance impacts neurophysiological processing in a manner that reduces the negative salient impact of own-face viewing and which, therefore, allows women to see themselves through new eyes, with enhanced confidence, femininity and attractiveness.

An alternative explanation consistent with the finding that neural responses to self-images become more similar to images of other faces following odour pairing, is that self-images became more other-like due to association with an unfamiliar stimulus. According to Baron and Bronfen [80] exposure to an unfamiliar odour in the context of an artificial laboratory experiment is somewhat novel and may increase arousal. Given the artificial context of most visual-olfactory research, the influence of familiarity is difficult to determine, although future research may be warranted to address this possibility.

The current study has several limitations. The study could have benefitted from having more than one fragrance condition to compare against the baseline condition of clean air. While a growing body of evidence highlights the enhancement of perceived attractiveness by socially relevant chemosignals [81,82], there is limited evidence regarding the impact of non-social odours on evaluation of facial attractiveness. The inclusion of different positively valenced fragrances would have allowed us to further elucidate the specificity of our results in relation to the fragrance chosen and its impact on positive subjective ratings of faces and associated electrophysiological responses. Similarly, it would be useful for future research to include negatively valenced odour stimuli. At present it is not possible to conclude whether our results are specific to the qualities of the fragrance presented here.

It is unclear whether the reported effects are specific to perception of a person. In a recent review, Spence [15] highlights that, despite evidence that olfactory cues can bias evaluations of a variety of other stimuli, such as artwork, such effects may be more pronounced for face perception given the biological relevance of odour for mate selection, which can serve as important socio-affective cues. Coupled with findings that affectively and semantically congruent stimuli are likely to be processed more efficiently [16], it is likely that such effects would be most pronounced for fragrances more strongly associated with human scents, such as body odour, perfumes and body washes. However, further exploration of crossmodal effects for incongruent odour-image pairings, and with a variety or non-human stimuli may warrant further exploration.

Additionally, participants rated the pleasantness and intensity of both the pleasant fragrance and clean air conditions, however, the pleasantness VAS scale was anchored from neutral to pleasant. The current study would have benefitted from anchoring the pleasantness scale from 'unpleasant' to 'pleasant' in order to determine whether the scent was truly perceived as pleasant, however, on debriefing the participants, all of the participants confirmed that they found the fragrance to be pleasant. Moreover, the decision to include 6 images in the self-condition, was driven by pilot testing which revealed limited differentiation between images if more angles were included. The imbalance between self- and other- image types was deemed appropriate as self-other ERP comparisons were not a target for analysis. However, the imbalance of stimuli across conditions could feasibly impact on the interaction effects seen between odour and image type effects and future research should investigate the role of stimuli frequency.

In conclusion, the current study showed that the presentation of a pleasant fragrance from a commercially available body wash is associated with enhanced ratings of facial attractiveness, confidence and femininity of self-face and other-face images. These cross-modal effects of pleasant fragrance were also represented at both early (N1), mid-latency (P3 and N2) and later stages (LPP) of electrophysiological processing of both self- and other-face images. Finally, there was evidence pointing to positive impact of the pleasant fragrance for modulating ERP differences associated with viewing self- compared to other-face images in mid-latency (N2 and P3) components. Taken together, these data indicate that the presence of the pleasant fragrance reduces critical processing of self-images and reduces the disparity between neurophysiological processing of self- and other faces that could clearly been seen when participants rated images in the presence of clean air. The enhanced evaluations of faces in the presence of the pleasant fragrance are reflected in augmented N1, N2, P3, and LPP components show similarities to neurophysiological evidence which highlighted these components for indexing of enhanced facial attractiveness. Notably, the current study was the first to observe N1 modulation in cross-modal fragrance-face interactions, which suggests that the studied pleasant fragrance can rapidly modulate N1 in response to neutral faces, impacting the earliest, bottom-up, stages of sensory processing. This important result shows the early impact of the pleasant fragrance on evaluation of faces at the subconscious level and the early latency of the N1 component suggests that the pleasant fragrance may positively impact early selective attention during the evaluation of faces. This finding, in combination with the behavioural ratings suggest pleasant fragrance can alter the processing of both own face and other people's faces at early stages of processing, and can alter evaluative judgments of attractiveness, confidence and femininity for both the self and others.

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Contributors

TG, AT, NF, CR, SSo, SSe and MS contributed to the development of the experimental design and planning of this work. NF and CR contributed to the development of the stimuli and materials. NF and CR contributed to the development of the behavioural rating task. JDO and HR conducted all of the data acquisition and pre-processing of EEG data. NF, JDO and HR conducted the ERP analysis. JDO and HR produced all figures and produced the final written manuscript, which was overseen by NF, CR, TG, AT and MS.

Conflict of interest

The work was funded by Unilever U.K. Central Resources Limited. Unilever provided the commercial products used in the study. TG, AT, MS, SSo and SSe work for Unilever. Unilever was not involved in the collection and analysis of the data.

Figure legends

Figure 1. A flow chart depicting a single trial of the experiment. Each trial consisted of 6, 1 second, face presentations, with a 1-second gap between each face presentation (i.e., each stream lasts 12 seconds). This was followed by a 2 second gap, after which one of the faces was presented again for 1 second and participants were prompted to rate this target image on two of a possible four rating scales presented sequentially; either attractiveness, confidence, femininity or glamorousness, using on-screen visual analogue scales.

Figure 2. Violin plots depicting distributions of subjective responses for ratings of attractiveness, confidence, femininity and glamorousness in pleasant odour conditions for self (dark purple) and other (light purple) images, and clean air condition with self (dark green) and other (light green) images. The coloured individual dots show data points from each participant, the bold black dot indicates the mean. The boxplots indicate the interquartile range (IQR) between the 25th and 75th percentile, and the whiskers represent 1.5 times IQR.

Figure 3. Butterfly plot of grand average waveforms to faces and corresponding scalp topographies for peak latencies. (A) Butterfly plot representing data for all electrodes across the whole period of the ERP averaged across all faces and fragrance conditions . Peak latencies of distinct ERP components (N1, N2, P3, LPP) are highlighted with arrows (98 ms, 200 ms, 280 ms, 380 ms and 580 ms). (B) Latency component 98 ms (N1). (C) Latency component 200 ms (N170). (D) Latency component 280 ms (N2). (E) Latency component 380 ms (P3). (F) Latency component 580 ms (LPP).

Figure 4. Impact of the pleasant fragrance on Facial ERPs at – N1 Component. (A) Whole head topographies maps for grand averaged N1 (75 – 115ms) with differences in negative activation within a middle frontal cluster of electrodes (E4, E6, E11, E12, E112 and E118

electrodes) when viewing facial images (self- and other-images) in the presence of the pleasant fragrance versus clean air. B) Grand Average ERP across a middle frontal cluster of electrodes between 75-115 ms. C) Bar chart of the mean N1 amplitudes of ERP waveform depicted above over epoch 75 – 115 ms from the same cluster of electrodes. The error bars shows the standard error.

Figure 5. Impact of pleasant fragrance on Facial ERPs – N2 Component. (A) Whole head topographic maps for grand averaged N2 (170 – 290ms) with differences in negative activation within a frontal-central cluster of electrodes (E4, E5, E6, E11, E12, E112, E118) when viewing facial images (self- and other-images) in the presence of pleasant fragrance versus clean air.(B) Grand average ERP waveform within a frontal-central cluster of electrodes across all subjects comparing other-images in the presence of pleasant fragrance (solid purple line) or a clean air control (solid green line) and self-images in the presence of pleasant fragrance (dashed purple line) or clean air (dashed green line). Epoch of interest 170 – 290 ms post feedback-onset highlighted in grey (C) Bar chart of mean N2 amplitude of ERPs over epoch 170 – 290ms from a cluster of fronto-central electrodes. The error bars show the standard error.

Figure 6. Impact of the pleasant fragrance on Facial ERPs – LPP Component. (A) Whole head topographic maps for grand averaged LPP (425 – 580 ms) displaying differences in positive activation within a cluster of right posterior electrodes (E95, E96, E100, E101, E107, E108). (B) Grand Average ERP waveforms comparing other-images in the presence of pleasant fragrance (solid purple line) or a clean air control (solid green line) and self-images in the presence of pleasant fragrance (dashed purple line) or clean air (dashed green line) across the right posterior electrode cluster for all participants between 425– 580 ms (highlighted in grey), (C) Bar chart of the mean electrical amplitudes of ERPs depicted above

over epoch 425 – 580 ms (N2) from the same cluster of electrodes. Error bars show the standard error.

Figure 7. Interactions between fragrance and self-other effects – N2. (A) whole head topographic maps displaying grand average activation between 170 – 290 ms for each fragrance and image condition type in central frontal cluster of electrodes (E6, E7, E13, E106, E112, Cz). (B) Grand average N2 ERP waveform displaying other-images in the presence of the pleasant fragrance (solid purple) or a clean air control (solid green) and self-images in the presence of the pleasant fragrance (dashed purple) or clean air (dashed green). Significant interval (170 – 290 ms) highlighted in grey. (C) Line graph of mean N2 amplitude of ERPs between 170 – 290 ms in central frontal cluster of electrodes.

Figure 8. Interactions between fragrance and self-other effects – P3. (A) Whole head topographic maps displaying differences in grand average P3 ERP activation between 315 – 400 ms in a fronto-central electrode cluster. (B) Grand average ERP waveform across all subjects comparing P3 activity to own face images in the presence of pleasant fragrance (solid purple line) or a clean air control (solid green line) and other-face images in the presence of pleasant fragrance (dashed purple line) or clean air (dashed green line). Epoch of interest 315 – 400 ms post feedback-onset highlighted in grey. (C) Line graph displaying mean amplitude of ERPs over epoch 315 – 400 ms from frontocentral electrodes cluster, showing reduced P3 amplitude for other-images across both fragrance conditions, and enhanced P3 positivity for self-images, which was reduced when the pleasant fragrance was present).

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