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Research article

# Simultaneous odour-face presentation strengthens hedonic evaluations and event-related potential responses influenced by unpleasant odour

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ABSTRACT

Odours alter evaluations of concurrently presented visual stimuli, such as faces. Stimulus onset asynchrony (SOA) is known to affect evaluative priming in various sensory modalities. However, effects of SOA on odour priming of visual stimuli are not known. The present study aimed to analyse whether subjective and cortical activation changes during odour priming would vary as a function of SOA between odours and faces.

Twenty-eight participants rated faces under pleasant, unpleasant, and no-odour conditions using visual analogue scales. In half of trials, faces appeared one-second after odour offset (SOA 1). In the other half of trials, faces appeared during the odour pulse (SOA 2). EEG was recorded continuously using a 128-channel system, and event-related potentials (ERPs) to face stimuli were evaluated using statistical parametric mapping (SPM).

Faces presented during unpleasant-odour stimulation were rated significantly less pleasant than the same faces presented one-second after offset of the unpleasant odour. Scalp-time clusters in the late-positive-potential (LPP) time-range showed an interaction between odour and SOA effects, whereby activation was stronger for faces presented simultaneously with the unpleasant odour, compared to the same faces presented after odour offset.

Our results highlight stronger unpleasant odour priming with simultaneous, compared to delayed, odour-face presentation. Such effects were represented in both behavioural and neural data. A greater cortical and subjective response during simultaneous presentation of faces and unpleasant odour may have an adaptive role, allowing for a prompt and focused behavioural reaction to a concurrent stimulus if an aversive odour would signal danger, or unwanted social interaction.

## 1. Introduction

It is well known that olfaction and emotion are tightly linked [1], and that hedonic judgement is a key aspect of olfaction [2,3]. As a result, odours are able to evoke emotional states, and affect perceptual processes in other modalities [4]. Previous studies have shown that pleasant and unpleasant odours influence evaluations of human faces [5–12]. However, the neural mechanisms that underlie such effects are not well established. The few EEG studies investigating such effects revealed that late ERPs (such as the N400 and the late-positive potential, LPP) evoked by faces were modulated by the presence of pleasant and unpleasant odours [11,12]. Functional magnetic resonance imaging (fMRI) data suggested that faces paired with pleasant fragrance activated the medial orbitofrontal cortex implicated in encoding the reward value of stimuli; whilst faces paired with unpleasant odour activated the amygdala, known to be involved in the processing of aversive stimuli [9]. Such changes in hedonic evaluations of visual stimuli and associated brain activation patterns are described as odour priming effects [13].

Whilst the phenomenon of evaluative priming is well established in vision and semantics (reviewed in [14]), little is known about the specific, temporal aspects of odour priming effects [13]. Studies investigating affective priming using words and pictures suggest that the temporal association between primes and targets, known as stimulus onset asynchrony (SOA) is of importance [15,16]. A recent meta-analysis of evaluative priming pointed to SOA as a factor influencing the

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strength of hedonic priming across various stimulus modalities [14]. The authors showed that SOA effects manifest in stronger changes in hedonic evaluation of targets with short, compared to long intervals between prime and target. However, there are no data on effects of SOA for olfactory priming.

To fill this gap in the literature, we investigate effects of two stimulus onset asynchronies on evaluative priming involving odours and faces. Further, we explore for the first time the neural manifestation of SOA in odour priming. In a previous study, we demonstrated odour-priming of neutral faces with both pleasant and unpleasant odours, when faces were presented one-second after odour offset. We also showed that pleasant odours increased the amplitude of face ERPs during the mid-late positive component (around 600 ms after face onset), and that pleasant and unpleasant odours respectively increased the amplitude of face ERPs in the left and right hemispheres, during the ultra-late positive component (around 900 ms after face onset) [11]. We now speculate about how the temporal variation between odour and face presentation affects both behavioural odour priming and neural responses to faces.

It has been proposed that early visual potentials (until approximately 300 ms after stimulus-onset) reflect unconscious stimulus perception, whilst later ones reflect conscious and controlled processing [17]. Hence, the late ERP effects observed in our previous study [11] may represent changes in the overt evaluation of faces that are necessary for priming after odour offset. During simultaneous odour-face presentation, odour-related effects may occur in earlier face-processing components (such as the N170, or N400) and be more representative of unconscious changes in face perception. At present, it is not known whether there are differences in effects of odours on hedonic evaluations of faces, either behaviourally or reflected in ERPs, when faces are presented during odour stimulation compared to when they are presented after odour offset.

The aim of this study was to investigate a direct comparison between odour priming with simultaneous and delayed presentation of odours and faces. In line with previous findings of SOA effects on the strength of evaluative priming [14], we hypothesised that odour-induced changes in evaluations of faces, early ERP components (e.g. N170, N400) and late ERP components (e.g. the LPP) may be stronger when faces appeared during the odour pulse compared to when they were presented one second after odour offset.

## 2. Methods

### 2.1. Participants

A total of 29 (10 male) participants aged 18 − 31 years (23.6 ± 3.8, mean ± standard deviation) took part in the experiment after responding to an advertisement. All but 4 subjects were right-handed. One participant withdrew from the experiment. EEG data from two participants were subsequently excluded due to excessive amounts of artifacts. Hence, behavioural data from 28 subjects, and EEG data from 26 (10 male) subjects were used in the analysis. People suffering from asthma or neurological disorders, particularly anosmia or epilepsy, were not permitted to take part in the study. Normal olfactory function was ascertained using the Sniffin'Sticks [18] test battery. Participants had to successfully identify a minimum of 9 out of the 12 odours in order to take part in the experiment. Participants were asked not to smoke, drink coffee or chew gum for two hours prior to the experiment, and were asked to minimise their use of fragranced products on the day. Participants were reimbursed for their time and travel expenses. The study was approved by the Research Ethics Committee at the University of Liverpool. All participants gave written informed consent in accordance with the Declaration of Helsinki.

### 2.2. Visual and olfactory stimuli

A total of 90 (45 male) neutral faces were used in the experiment. Due to the large number of faces needed to satisfy the number of trials required per condition, faces were selected from three databases. Forty-two (24 male) faces were obtained from the NimStim Set of Facial Expressions [19]. Forty-three (21 male) faces were obtained from the Japanese and Caucasian Neutral Faces [JACNeuf; [20]. A further five female faces were selected from the Gur/Kohler images, acquired according to Gur et al. [21] and referenced in Kohler et al. [22]. All face images were frontal views, in colour, with a consistent light background and similar dimensions. During the screening session, participants rated the perceived pleasantness of the facial expressions of all 90 faces (on a scale ranging from 0–very unpleasant to 100–very pleasant) in order to ensure that they were perceived as neutral. The mean face pleasantness rating was 50.3 ( ± 8.4).

There were three odour conditions in the experiment; pleasant, unpleasant and a neutral, 'clean air' control. Methylmercaptan (1% dilution in Propylene Glycol), a rotten cabbage-like odour, was selected for the unpleasant condition. Jasmine odour (no dilution) was selected for the pleasant condition. These dilutions were matched on perceived intensity based on data from a previous experiment [Mean intensity rating of Jasmine: 56.33 ± 15.83, mean intensity rating of Methylmercaptan: 61.34 ± 17.68; 11].

### 2.3. Procedure

Procedures for odour administration, presentation of the experimental task, recording EEG and baseline odour ratings were identical to those described in previous papers [11,23].

The experimental task was split into four blocks of 45 trials (180 trials in total). Trials were pseudo-randomly ordered such that each of the 90 faces used in the task appeared twice: once under each SOA condition, with the same odour both times. The odour with which a given face was paired was counterbalanced across subjects. Any given face never appeared more than once in one block. Odour presentation was also pseudo-random, such that all three odours were presented across all four blocks, but no two consecutive trials used the same odour. Fig. 1 shows a flowchart of the trial procedure. Each trial began with a resting interval during which participants viewed a white cross on a black background. The duration of this interval was dependent upon the triggering of the odour pulse; the experimenter observed participants' respiratory waveforms, and manually triggered the odour pulses at the very onset of inspiration. In half of the trials, a three-second odour pulse was released, during which time participants viewed a black screen. The screen remained black for a further one-second resting interval after odour offset, before a neutral face was displayed on-screen for 300 ms (SOA 1). The other half of the trials were identical, apart from that the neutral face was displayed on-screen during the three-second odour pulse, at 2000 ms after odour onset (SOA 2). In both conditions, a resting interval with a black screen then preceded a rating scale prompting participants to rate the pleasantness of the neutral face (from 0–very unpleasant to 100–very pleasant). Once participants had responded, a second scale prompted them to rate the intensity of the odour administered in that trial (0–no odour to 100–very intense odour). After their response, the next trial began.

### 2.4. Analysis

Odour ratings taken before and after the task were analysed using paired *t*-tests. Data from the experimental task was analysed using 2 × 3 repeated measures ANOVA to observe differences in face pleasantness ratings and odour intensity ratings, with SOA and odour condition (pleasant, unpleasant, and neutral) as independent factors. All behavioural data were analysed using SPSS v. 22 (IBM Inc., USA).