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Research report

Cerebral bases of emotion regulation toward odours: A first approach

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HIGHLIGHTS

- Regulation of odour-induced emotions results in higher activation of the dorsolateral prefrontal cortex and the anterior insula.
- Regulation of odour-induced emotions results in mild lower activation of the amygdala.
- Orbitofrontal cortex is less activated during regulation compared to maintain emotions.
- Regulation of positive odour-induced emotions results in activation of the supplementary motor area.
- Regulation of negative odour-induced emotions results in activation of the posterior cingulate gyrus.

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ABSTRACT

Emotion regulation is defined as an important mechanism for human adaptation. fMRI studies have recently highlighted its neural bases but most research uses visual stimulation to induce emotion, none of them using odorant stimulations. Nevertheless, olfaction is intimately linked to emotional processes, sharing some same neural bases and thus constitutes a valuable emotion-inducer in experimental conditions. The present study aims to determine the cerebral areas which might be involved in down-regulation, using pleasant and unpleasant odours as emotion-inducers. Eighteen subjects were scanned during 2 sequences of 12 stimulations, each with either a pleasant or an unpleasant odour. For one sequence, subjects were instructed to naturally experience their emotion induced by odour inhalation and for the other one, to decrease the intensity of their emotion. Consistent with previous work using emotion-inducers, emotion regulation resulted in higher activations of the dorsolateral prefrontal cortex and the anterior insula, but in lower activation of the amygdala. However, some areas (the posterior cerebellum and the orbitofrontal cortex) are less activated during regulation compared to maintain and thus appear to be specific to odorant stimulations. Finally the hedonic valence of the odour determines activations in different brain areas such as the supplementary motor area and the posterior cingulum. Thus, this study suggests abilities to regulate emotion in response to odours, involving brain areas usually described in the literature for other emotional stimuli, but also specific areas depending partly of the hedonic valence of the odour.

1. Introduction

Airborne chemical stimuli constitute a continuous olfactory background in the everyday life environment. Our sense of olfaction is able to detect among these stimuli potential signals of interest and helps to cue an appropriate response. In particular, odours can colour perceptions about the world both positively or negatively through emotion processes and thus can modulate mood and behaviour [1,2]. This close relationship between olfaction and affective processing can be explained by the strong overlap between olfactory pathways and limbic brain structures. Projections from the olfactory bulb connect directly to the periamygdaloid region, subnuclei of the amygdala (corticomedial group) which form parts of the primary olfactory cortex [3,4]. Indeed, odours are able to more strongly modulate neuronal response within the amygdala than visual stimuli [5]. Other than the primary olfactory cortex, the

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orbitofrontal cortex is well identified as part of the secondary olfactory cortex as well as a nexus for sensory integration, modulation of autonomic reactions and decision-making involving emotional components [6,7]. Other brain structures, described in cerebral imaging studies as being recruited by olfactory perception, are also involved in different emotion processing: particularly the hippocampal formation, the insula and the anterior cingulate cortex [8].

Emotions are necessary and helpful in numerous adaptive behaviours as they guide responses and decision-making processes. However, they can cause problematic situations when occurring, for example, at an inappropriate time or intensity level. Thus in these situations, emotion regulations can be of interest as a part of the emotional processes themselves. A growing literature has documented the abilities in emotion regulation in adults, children and the elderly as well as in patients suffering from mood disorders [9]. Typically, emotion regulation tends to decrease negative affect as well as increase or maintain positive affects [10]. Emotion regulation includes extrinsic and intrinsic processes implied in monitoring, evaluating and modifying emotions [11]. Automatic and voluntary emotion regulation can be distinguished. Voluntary emotion regulation is based on different cognitive strategies and the best-studied forms are attentional control and reappraisal [12], which are both supposed to depend greatly on individual resources in attention flexibility. More recently, cerebral imaging studies have shed light on the neural bases implied in these cognitive strategies, particularly distraction and reappraisal, and they point to a decreasing activity in limbic structures, particularly in the amygdala, and an increasing activity in the prefrontal cortex (PFC) during efficient emotion regulation [13–16]. Nonetheless, these studies focused mainly on cognitive reappraisal strategies, although the brain processes could be different for other strategies of emotion regulation [12,17–19].

Most studies on emotion regulation are based on visual stimuli (usually upsetting, disgusting or frightening pictures or films). To date, no study in cerebral imaging has investigated regulation abilities towards odour-generated emotion. Indeed, only one recent study [20] questioned the possibility of efficient emotion regulation with odours as stimuli. Subjects were instructed to use cognitive reappraisal strategies to enhance or down-regulate emotions generated by unpleasant odours. Self-evaluation of emotion was rated and the startle reflex was recorded. This study shows a delayed time course of emotion regulation towards odours compared to pictures and suggests that cognitive reappraisal of odour-evoked emotion may be limited when compared with that of picture-evoked emotion. Nevertheless, some abilities to modulate odour-generated emotions by cognitive processes have been demonstrated by de Araujo and his colleagues [21]: in their experiment, the subjects rated differently the pleasantness of a same odour (isovaleric acid combined with cheddar cheese flavour) according to the given semantic labels of “body odour” or “cheddar cheese”. Furthermore, these semantic labels also modulated the activations in some brain areas in response to this odour (i.e. anterior cingulate cortex, orbitofrontal cortex, amygdala). This study demonstrates the possibility of modulation of odour-generated emotion by cognitive (semantic) processes but does not respond to the question of voluntary emotion regulation in response to odours.

The present study aims to investigate by fRMI the brain areas which may be involved in the emotion regulation of pleasant and unpleasant odours. In this framework, we will firstly examine whole brain activations with odour stimulations contrasted with rest periods to ensure involvement of brain areas usually described in the literature in such experimental conditions. Secondly, we will examine the whole brain activations revealed by the contrast between regulated and non-regulated odour-induced emotions for both odorants. Thirdly, the analyses will focus on regions of interest (ROI) identified as important components of the secondary olfactory cortex to identify activations or modulations during the emotion regulation task.

2. Materials and methods

2.1. Participants

Participants were 24 right-handed students (9 females) at the University of Besançon (France). They were aged between 20 and 26 years and non-smokers. All participants were healthy, free of head colds or nasal allergies. They had no history of olfactory impairment and they were not under any regular medication (except for oral contraceptives for some of them). This study was reviewed and approved by the local ethics committee (Comité de Protection des Personnes Est II) and declared to the national authority (N° UF: 1013; DGS 2006/0494) in accordance with the Declaration of Helsinki on biomedical research. Participation required the completion of a written informed consent form and a medical examination prior to the fMRI session. All the subjects were scored for their olfactory sensitivity with the Sniffin' sticks test [22] to ensure that their sense of smell was appropriate for age. They obtained a mean score of 9.72 (sd = 0.60) for their olfactory threshold which is better than the norm [22].

2.2. Odorants and odour delivery

Two odours were used during the fMRI session. The first one (supplied by Across-Organics®), isoamyl acetate (IAA, banana-like odour) is usually considered to be pleasant [23] and the second one (Sigma-Aldrich®), thioglycolic acid (TA, rotten egg odour) is usually considered to be unpleasant [24].

These odours were delivered via a multi-channel custom-built olfactometer. This olfactometer was suitable for the fMRI environment and generated odours with a rapid and steady on-off time (for further details, see Andrieu et al., 2014 and Billot et al., 2011 [25,26]). A constant flow of odourless air (1.4 L min^{-1}) was delivered to the subject through tubing with an output under the subject's nose (distance of 2 cm between output and the nostrils). The use of solenoid valves enabled odorant conditions to be switched with the air flow passing through bottles containing the odorants (1 mL), either IAA (50% diluted in diethyl phthalate: 171 ppm) or TA (4% diluted in diethyl phthalate: 2.8 ppm). These supra-threshold concentrations were chosen following preliminary tests on a panel of twenty undergraduate students (both males and females) to obtain approximately the same self-ratings of intensities. The measures of mean values on a Likert scale (from 0, low intensity to 9, high intensity) were 6.2 (sd = 1.96) for IAA and 5.7 (sd = 2.11) for TA. A Wilcoxon signed ranks test showed no difference between the intensity ratings of the two odorants ($W = 31.5$, $Z = 0{,}978$, $p = 0{,}328$). Although these odours are potentially olfactotrigeminal combinations, they were used with low concentrations and thus it can be assumed that the trigeminal component of the stimulation was weak. None of the subjects reported the typical feelings induced by trigeminal stimulations [27].

2.3. Experimental paradigm

2.3.1. Instructions to the subjects and training session

As odour-evoked emotion regulation is poorly documented, no particular cognitive strategy was prescribed to the subjects. They were only told that the aim of the study was to investigate the brain processes related to abilities to consciously decrease odour-triggered emotions. They were also told that they would have to smell a pleasant and an unpleasant odour. The labels of the odours were not mentioned as this can modulate the neural