



Neural responses during the anticipation and receipt of olfactory reward and punishment in human

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ABSTRACT

Pleasure experience is an important part of normal healthy life and is essential for general and mental well-being. Many neuroimaging studies have investigated the underlying neural processing of verbal and visual modalities of reward. However, how the brain processes rewards in the olfactory modality is not fully understood. This study aimed to examine the neural basis of olfactory rewards in 25 healthy participants using functional magnetic resonance imaging (fMRI). We developed an Olfactory Incentive Delay (OLID) imaging task distinguishing between the anticipation and receipt of olfactory rewards and punishments. We found that the pallidum was activated during the anticipation of both olfactory rewards and punishments. The bilateral insula was activated independently from the odours' hedonic valence during the receipt phase. In addition, right caudate activation during the anticipation of unpleasant odours was correlated with self-reported anticipatory hedonic traits, whereas bilateral insular activation during the receipt of pleasant odours was correlated with self-reported consummatory hedonic traits. These findings suggest that activity in the insula and the caudate may be biomarkers of anhedonia. These findings also highlight a useful and valid paradigm to study the neural circuitry underlying reward processing in people with anhedonia.

1. Introduction

Pleasure experience is an important part of normal healthy life and is crucial for general and mental well-being (Berridge and Kringelbach, 2008; Croy et al., 2014b; Kringelbach, 2005). Currently, it is widely accepted that the pleasure cycle is a construct involving three distinct components, i.e., learning, anticipating (or wanting) and consummating (or liking) (Gard et al., 2006; Knutson and Greer, 2008; Kringelbach and Berridge, 2009; Kringelbach et al., 2012). Learning is a phase that one learns and updates predictions about future rewards based on past experiences (Berridge et al., 2009; Kringelbach and Berridge, 2009; Kringelbach et al., 2012). Consummatory pleasure is the emotional state when directly experiencing pleasurable events, while anticipatory

pleasure refers to the emotional state when experiencing a motivated and goal-directed behaviour for future pleasurable events (Berridge et al., 2009; Knutson and Greer, 2008; Kringelbach and Berridge, 2009). Previous studies have explored the neural correlates of anticipation of various kinds of rewards, such as money (Knutson et al., 2001; Yan et al., 2016), food (McClure et al., 2007; O'Doherty et al., 2002; Pelchat et al., 2004), social feedback (Izuma et al., 2008; Lin et al., 2012; Richey et al., 2014) and affect-laden pictures (Chan et al., 2016), and identified important brain regions that are activated in reward anticipation, including the striatum (Izuma et al., 2008; Knutson et al., 2001, 2003; Lin et al., 2012; O'Doherty et al., 2002), the insula (Tsurumi et al., 2014) and the pallidum (Bischoff-Grethe et al., 2015). However, most of the neuroimaging studies on pleasure experience have focused

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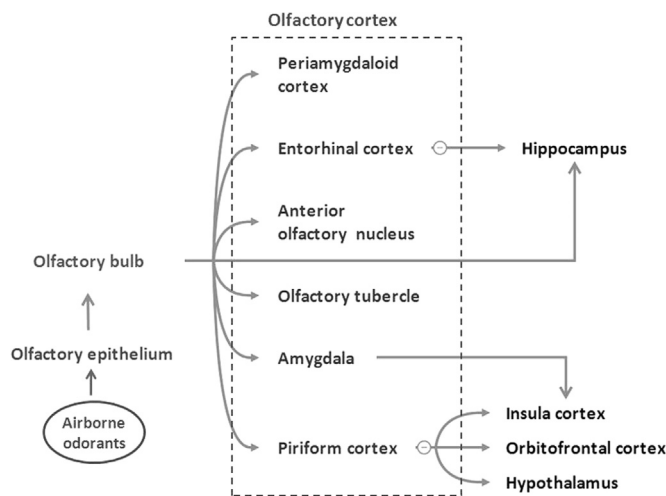


Fig. 1. An overview of the olfactory pathways and networks.

on anticipation of verbal or visual stimuli. It is not fully understood how the brain processes pleasure experience in the olfactory modality.

It is known that olfactory processing has several major differences from other sensory modalities. Neuroanatomically, olfaction and emotion processing share neural substrates and connectivity with the olfactory pathways bypassing the thalamus and projecting directly into limbic structures in the brain (Dijksterhuis et al., 2002; van Hartevelt and Kringsbach, 2012). An overview about the olfactory pathways and networks adapted from Parma, Wilson, and Lundström (2017) and Mainland, Lundström, Reisert, and Lowe (2014) can be found in Fig. 1. A number of studies have examined the neural basis of consummatory olfactory pleasure. Our previous meta-analysis found that olfactory hedonic processing activated the bilateral parahippocampal gyrus/amygdala, the orbitofrontal cortex (OFC), the bilateral cingulate gyrus, the right lentiform nucleus/pallidum and the right insula (Zou et al., 2016). However, few studies have addressed the issue of which brain regions are involved during the anticipation of an olfactory reward. It is much more difficult for a person to imagine olfactory stimuli than visual ones (Royet et al., 2013). Therefore, the anticipation of olfactory stimuli may be different from visual and auditory stimuli.

To investigate the underlying neural mechanism associated with both the anticipation and receipt of olfactory stimuli, we adopted an incentive delay task which was specifically developed to assess response to anticipation and receipt of rewards and punishments from various types of stimuli. In the present study, we developed the Olfactory

Incentive Delay (OLID) task to assess the neural basis of the anticipation and receipt of olfactory rewards and punishments. During the anticipation phase, we specifically examined regions which had been found to be activated by the anticipation of reward or punishment in previous studies, such as the striatum, the insula and the pallidum. We hypothesized that the above-mentioned regions would also be activated by olfactory rewards and punishments. We also hypothesized that we would find odour-related activation in the amygdala, the orbitofrontal cortex (OFC), the cingulate gyrus, the pallidum and the insula, brain regions that have been identified in our previous meta-analysis (Zou et al., 2016). Moreover, since hedonic traits have been found to be significantly associated with reactivity of the mesolimbic and paralimbic reward systems in non-clinical participants (Keller et al., 2013), we also explored the relationship between brain activation during the anticipation and receipt of olfactory stimuli and self-reported hedonic traits.

2. Material and methods

2.1. Participants

Twenty-five healthy ethnic Chinese participants (13 females and 12 males) with a mean age of 19.84 years ($SD = 1.60$) participated in the present study. They were all right-handed and did not have any ear-nose-throat problems. Potential participants with a self-reported personal history of substance abuse, brain injury and personal or family history of neuropsychiatric disorders were excluded from this study. The present study was approved by the Ethics Committee of the Institute of Psychology, the Chinese Academy of Sciences. We obtained written informed consents from all participants.

2.2. Olfactory incentive delay task

The OLID task (see Fig. 2) was used to examine the neural substrates involved in the anticipation and receipt of olfactory rewards and punishments. This task was adapted from the Monetary Incentive Delay (MID) task (Knutson et al., 2001, 2003) and included 90 18 s-trials divided into three sessions. There were 30 trials per condition type and trial types were pseudo-randomly ordered within each session. Each of the trial began with the presentation of a valenced cue for 250 ms, indicating the condition (reward, punishment or neutral) of this trial. Next, an anticipatory delay was presented for 2000–2500 ms, followed by a target stimulus (a white “★” on a black background), which instructed the participant to respond as quickly as possible. Target durations varied individually as a function of the participant's recent

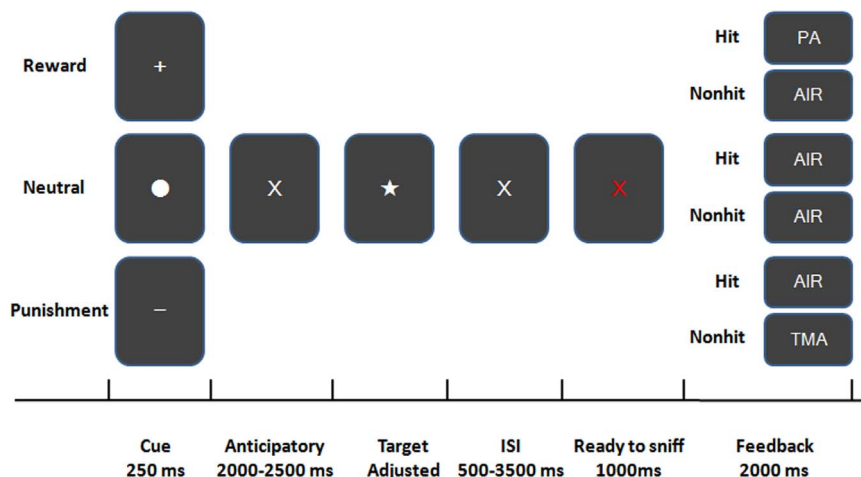


Fig. 2. Sample trials of the Olfactory Incentive Delay(OLID) task under reward, punishment, and neutral conditions. Note. PA: Pentyl acetate (banana); TMA: Trim ethylamine (rotten fish); AIR: air; ISI: interstimulus interval.

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