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Posterior resting state EEG asymmetries are associated with hedonic valuation of food

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ABSTRACT

Research on the hedonic value of food has been important in understanding the motivational and emotional correlates of normal and abnormal eating behaviour. The aim of the present study was to explore associations between hemispheric asymmetries recorded during resting state electroencephalogram (EEG) and hedonic valuation of food. Healthy adult volunteers were recruited and four minutes of resting state EEG were recorded from the scalp. Hedonic food valuation and reward sensitivity were assessed with the hedonic attitude to food and behavioural activation scale. Results showed that parieto-occipital resting state EEG asymmetries in the alpha (8–12 Hz) and beta (13–30 Hz) frequency range correlate with the hedonic valuation of food. Our findings suggest that self-reported sensory-related attitude towards food is associated with interhemispheric asymmetries in resting state oscillatory activity. Our findings contribute to understanding the electrophysiological correlates of hedonic valuation, and may provide an opportunity to modulate the cortical imbalance by using non-invasive brain stimulation methods to change food consumption.

1. Introduction

Research on the hedonic value of food has been important in understanding the motivational and emotional correlates of eating behaviour (for reviews see Berridge, 1996; Murray et al., 2014). Hedonic eating is defined as the intake of food in the absence of metabolic demands in order to obtain a positive effect on emotion and mood (Berthoud, 2011; Ely et al., 2013). This particular form of eating is typically associated with the consumption of high caloric food containing high levels of fat, sugar and salt (Burgess et al., 2014). It comes therefore as no surprise that hedonic eating is considered a risk factor for developing obesity and eating disorders, and has gained considerable interest in recent years (Berthoud, 2011).

While much is known about the brain's metabolic-related homeostatic control mechanisms of food intake, there is only limited knowledge about the attention and neurobiological mechanisms of (non-homeostatic) hedonic eating. Several studies have found relations between approach-related motivation, attention-related food intake and hedonic eating. In general, people demonstrate an attention bias towards appetitive food cues and an attention bias away from food cues associated with disgust (Piqueras-Fiszma et al., 2014). The relation between approach-avoidance behaviour and attention is further illustrated by results showing that chocolate-cravers respond faster to chocolate food items paired with approach-related words and slower to pairings of non-chocolate food items with avoidance-related words (Kemps et al., 2013). Furthermore, reducing activity in the brain's reward circuit by administration of the dopaminergic type 3 receptor antagonist, GSK598809, attenuates approach-related responses to appetitive food cues in overweight and obese individuals (Mogg et al., 2012). This finding corroborates with functional magnetic resonance imaging (fMRI) results showing that obese binge eaters show an increase of left relative to right frontal activity when exposed to palatable food as compared to lean and obese non-binge eaters (Karhunen et al., 2000). Moreover, patients with anorexia nervosa show enhanced visual and cognitive processing of food stimuli (Godier et al., 2016), but nonetheless demonstrate reduced approach-related actions related to food intake (Veenstra and de Jong, 2010). Results on cortical electroencephalogram (EEG) asymmetries in the theta (4–7 Hz) frequency range of patients with anorexia nervosa suggest deficits in right hemispheric information processing during multisensory integration (Grunwald et al., 2004). Since anorexia nervosa has been conceptualized as a reward-related disorder, hemispheric EEG asymmetries may contribute to brain reward processes related to food in normal and psychopathological conditions (Monteleone et al., 2016).

Studies addressing the neurobiological correlates of hedonic eating are important as they may have implications for the prevention and

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treatment of eating disorders (Val-Laillet et al., 2015). Evidence suggest that hedonic eating is associated with activity in the brain's cortico-limbic circuits (Berthoud, 2011; Shin et al., 2009). For example, fMRI research has demonstrated increased blood oxygen level-dependent (BOLD) activity in reward-related limbic areas when fasting healthy volunteers are presented with high caloric foods (Goldstone et al., 2009). In addition, reward signals correlated positively with the subjective appreciation of the food, supporting the notion that motivational and emotional factors contribute to the appreciation of food (Berthoud, 2011). Furthermore, stronger activation of reward structures in the limbic system when looking at high caloric food also increases approach-related motivation to obtain the food (García-García et al., 2013).

Approach-related behaviour has been studied using EEG within the cortical lateralization model of motivational direction (Gray, 1970, 1987; Smillie et al., 2006; Van Honk and Schutter, 2006). According to this model approach-related behaviour is linked to activity of the left frontal cortex, whereas avoidance-related behaviour is associated with activity of the right frontal cortex. Resting state EEG asymmetries have been found to represent a neural state associated with approach- and avoidance-related motivational dispositions. Previous research has demonstrated that resting state EEG asymmetries are associated with extraversion (Wacker and Gatt, 2010), aggression (Hofman and Schutter, 2012), risk taking (Schutter et al., 2004), neuroticism (Chi et al., 2005), emotion regulation (Hannesdóttir et al., 2010), and stress responding (Quaedflieg et al., 2015). In particular, anterior resting state EEG asymmetries between the left and right hemisphere in the alpha (8–12 Hz) range predict approach- and avoidance-related behaviour. Especially, reduced alpha activity which is indicative for increased neural activity of the left frontal cortex has been linked to behavioural measures of approach (Coan and Allen, 2003; Harmon-Jones, 2003; Sutton and Davidson, 1997; Tomarken et al., 1990). In addition, recent research showed that higher resting state left-to-right cortical excitability levels are correlated to left-dominant cortical beta (13–30 Hz) EEG asymmetries in the frontal cortex and more reward-driven approach-related behaviour (Schutter et al., 2008). Increased frontal beta oscillations have been found in obese patients with binge-eating disorders (Tammela et al., 2010). Further support for the relation between frontal EEG asymmetries and approach- and avoidance-related behaviour comes from a study showing that restrained eaters display right-sided frontal alpha EEG asymmetry (Silva et al., 2002). In addition, greater left-to-right frontal alpha EEG asymmetries have been found to relate to behavioural disinhibition and increased approach-related responsivity to food in individuals with obesity (Ochner et al., 2009). Thus in addition to the links between eating disorders, reward processing and hedonic valuation of food (Davis et al., 2008; Soussignan et al., 2011; Witt and Lowe, 2014), resting state EEG asymmetries may provide for an electrophysiological correlate.

As noted earlier greater right-to-left theta asymmetries during multisensory integration processing have been found in patients with anorexia nervosa, although its relation to reward and approach-related behaviour remains unclear (Grunwald et al., 2004). In addition the involvement of the frontal cortical regions in approach-related behaviour, electrocortical asymmetries have also been proposed for the perceptual regions located in the posterior parts of the cerebral cortex (Schutter et al., 2001; Van Honk et al., 2003). For example, dominant left-sided processing as a result of disrupting right parietal cortical processing has shown to increase approach-related behaviour in both rats and humans (Crowne et al., 1987; Van Honk et al., 2003). Knowing that parietal-occipital regions are involved in the processing of appetitive food stimuli (Carretié et al., 2000; Hume et al., 2015), it is not unreasonable to assume that posterior cortical EEG asymmetries may also be predictive for the hedonic valuation of food.

The aim of the present study was therefore to investigate whether cortical EEG asymmetries are predictive of the hedonic valuation of food. In keeping with the motivational direction model of cortical lateralization, we hypothesized that a more positive attitude towards food would be associated with lower left as compared to right-sided EEG activity in the alpha and beta frequency range.

2. Material and methods

2.1. Participants

Thirty-six right-handed non-smoking volunteers (24 males/12 females) were students recruited from the Radboud University Nijmegen and the Hogeschool van Arnhem-Nijmegen. Subjects were aged between 18 and 35 years (mean $\pm$ SD, 22 $\pm$ 3.49) and had a Body Mass Index (BMI) between 18 and 30 (mean $\pm$ SD, 22.6 $\pm$ 2.40). Body weight was stable ($\pm$5 kg) in the past two months. Subjects were free of medication with the exception of oral contraceptives in the female participants. Pregnancy or breastfeeding were exclusion criteria. None of the participants reported a history of psychiatric or neurological conditions, and all had normal or corrected-to-normal visual acuity. Participants had not followed a diet in the past six months. Sample size was based on previous studies on the relation between self-report questionnaires and EEG asymmetries (e.g., Coan and Allen, 2003; Harmon-Jones and Allen, 1997; Jacobs and Snyder, 1996; Schutter et al., 2008). Volunteers provided informed consent prior to the study, and received payment for participation. The study was in accordance with the ethical standards of the Declaration of Helsinki and approved by the local ethical committee of the Faculty of Social Sciences of the Radboud University Nijmegen, the Netherlands.

In the present study a strict exclusion criterion regarding minimum or maximum BMI score was not applied. However, participants had to have a stable body weight ($\pm$5 kg) over the last two months and had not followed a diet in the last 6 months. As a result our sample did not include participants with a BMI higher than 30 or lower than 18. Partial correlations controlling for BMI did not influence the presently reported relations between hedonic food valuation and posterior alpha EEG asymmetry eyes open, $r = -0.59$, $p = 0.002$, and hedonic food valuation and posterior beta EEG asymmetry eyes open, $r = -0.45$, $p = 0.015$.

2.2. Questionnaires

2.2.1. Hedonic attitude to food (HTAS)

The Dutch version of the Health and Taste Attitudes Scales (Roininen and Tuorila, 1999; Roininen et al., 2001) was used to assess people's hedonic attitudes towards food. Hedonic attitude is measured with three subscales, "craving for sweet foods", "using food as a reward", and "pleasure" and is predictive for intentional food choices (Stubenitsky et al., 1999). The hedonic attitude to food scale consists of six questions and responses are collected on a 7 point Likert scale (1 = strongly disagree; 7 = strongly agree). The HTAS hedonic valuation of food scale has a Cronbach's alpha reliability index of 0.65 (Roininen and Tuorila, 1999; Chen, 2013).

2.2.2. Approach-related motivational tendencies

Carver and White's (1994) behavioural activation system (BAS) self-report scale was administered to measure motivational tendencies.

The BAS scale captures individual differences in the way organisms respond to biologically relevant information (Gray, 1987; Carver and White, 1994; Sutton and Davidson, 1997). In particular, the BAS is sensitive to signals of reward and appetitive stimuli, and linked to approach-related behaviour. High BAS scores are related to approach-related motivation, and in particular the subscale reward sensitivity (Sutton and Davidson, 1997) measures reward-related approach motivational tendencies. This subscales consists of 5 items and responses are collected on a 4 point Likert scale (1 = strongly agree; 4 = strongly disagree). The test-retest correlations for the BAS scale range from 0.59