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Disgust evoked by strong wormwood bitterness influences the processing of visual food cues in women: An ERP study

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The perception of intense bitterness is associated with disgust and food rejection. The present cross-modal event-related potential (ERP) study investigated whether a bitter aftertaste is able to influence affective ratings and the neuronal processing of visual food cues. We presented 39 healthy normal-weight women (mean age: 22.5 years) with images depicting high-caloric meat dishes, high-caloric sweets, and low-caloric vegetables after they had either rinsed their mouth with wormwood tea (bitter group; n = 20) or water (control group; n = 19) for 30s. The bitter aftertaste of wormwood enhanced fronto-central early potentials (N100, N200) and reduced P300 amplitudes for all food types (meat, sweets, vegetables). Moreover, meat and sweets elicited higher fronto-central LPPs than vegetables in the water group. This differentiation was absent in the bitter group, which gave lower arousal ratings for the high-caloric food.

We found that a minor intervention ('bitter rinse') was sufficient to induce changes in the neuronal processing of food images reflecting increased early attention (N100, N200) as well as reduced affective value (P300, LPP). Future studies should investigate whether this intervention is able to influence eating behavior.

1. Introduction

In our daily lives we are constantly exposed to visual food cues. Advertisements in the media, in supermarkets, and in restaurants present food images in the most favorable and appetizing manner possible. It is not surprising that individual food cue reactivity can predict increased eating and subsequent weight gain (see meta-analysis by Boswell & Kober, 2016). For countries with a food surplus this has become a real health issue as indicated by increased levels of overweight and obese people, and associated comorbid conditions (Boswell & Kober, 2016).

Studies using event-related potentials (ERPs) have extensively studied food cue reactivity. This research revealed that our attentional system is tuned to detect foods, especially those providing high energy, and to differentiate food from nonfood items. The viewing of pictures depicting food elicits enhanced P300 and late positive potentials (LPP) (e.g., Blechert, Goltsche, Herbert, & Wilhelm, 2014; Sarlo, Übel, Leutgeb, & Schienle, 2013; Stockburger, Renner, Weike, Hamm, & Schupp, 2009; Stockburger, Weike, Hamm, & Schupp, 2008). Moreover, high-caloric food provokes more pronounced late positivity than low-caloric food (e.g., Asmaro et al., 2012; Toepel, Knebel, Hudry, Le Coutre, & Murray, 2009).

The P300 and the LPP are positive voltage deflections distributed across the scalp (Schupp et al., 2000). The P300 can be found between 300 and 500 ms after stimulus onset, the LPP can last up to 6000 ms (Cuthbert, Schupp, Bradley, Birbaumer, & Lang, 2000). Late ERPs like these can be interpreted as indicators of emotional significance (Olofsson, Nordin, Sequeira, & Polich, 2008). Maximum amplitudes are usually found across parietal sites, reflecting activation of the visual association cortex. Therefore, late ERPs reflect the amount of visual attention and processing resources devoted to a stimulus (for a review on motivated attention, see Bradley, 2009). Whereas P300 potentiation is considered an indicator of a phasic increase of attention (e.g., Weinberg, Hilgard, Bartholow, & Hajcak, 2012), the LPP reflects a sustained increase, which can be modified by different cognitive strategies. Therefore, the LPP has been conceptualized as an index of emotion regulation. In particular, frontal late positivity can be modulated by altered stimulus appraisal (for a review, see Hajcak, MacNamara, & Olvet, 2010). EEG

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source localization studies have demonstrated that frontal LPPs originate from prefrontal cortex regions and the insula (e.g., Scharmüller, Leutgeb, Schäfer, Köchel, & Schienle, 2011).

Visual food cues function as starting signals for eating. As pointed out before, the high density of such cues in our environment increases the risk of overeating (Boswell & Kober, 2016). This risk might be reduced by the implementation of stop signals, which, for example, are provided by bitter-tasting substances of high intensity. Because bitterness is an indicator of potential food toxicity (e.g., spoiled meat and some poisonous berries do taste bitter), its perception elicits protrusion of the tongue and other protective reactions that prevent ingestion (Meyerhof, Behrens, Bufe, & Kuhn, 2005). Although intense bitterness is generally perceived as aversive, individuals differ markedly regarding how (even slightly) bitter foods and liquids taste to them. This also influences their food choice (Bartoshuk, Duffy Valerie, & Miller, 1994).

Bitterness sensitivity, the ability to detect bitterness, is linked with the basic emotion of disgust (Schienle, Arendasy, & Schwab, 2015). The sensory quality 'bitter' is usually rated as disgusting, especially in high intensities, and individuals who score high on questionnaires for the assessment of disgust proneness (a personality trait which describes the temporally stable tendency to experience disgust across different situations) are more sensitive to bitter compounds, such as 6-*n*-propylthiouracil (PROP; e.g., Herz, 2011). Furthermore, bitter tastes are able to elicit the typical facial disgust expression with the raising of the upper lip and the protrusion of the tongue, which reflects aversive gape (Berridge, 2000). The facial disgust expression can be seen as functional in terms of rejecting health-threatening food, and the most distinct somatic concomitant of disgust nausea inhibits ingestion. Disgusting objects should not enter the body and therefore need to be spat out. Hence, disgust first evolved to motivate food rejection and later on expanded to other domains (Rozin, Haidt, & McCauley, 2008, pp. 757–776).

The present study sought to determine whether a bitter aftertaste affects the pleasantness and intensity of visual food cues, as assessed with ERPs. The female participants were randomly assigned to one of two groups. The 'bitter group' tasted wormwood tea, while the 'control group' rinsed their mouth with water. The participants of both groups viewed images depicting food from different categories: high-caloric meat dishes (e.g., burgers), high-caloric sweets (e.g., cakes), and low-caloric vegetarian food (e.g., boiled beans). We hypothesized that the bitter taste would lead to reduced valence, arousal and appetite ratings of the food pictures and decreased late positivity (P300, LPP). As bitterness has a higher predictive value of food toxicity for meat and milk products compared to vegetables (Glendinning, 1994), we predicted that the dampening effect should be most pronounced for the high-caloric foods.

2. Methods and materials

2.1. Sample

Thirty-nine women were randomly assigned to one of two groups. The bitter group (BG; n = 20) tasted wormwood tea, while the control group (CG; n = 19) received water. The two groups did not differ in mean age (M ± SD) ($t(37) = -1.30$, $p = 0.20$; BG: 21.9 years ± 1.9; CG: 23.0 years ± 3.4), education ($U = 179$, $p = 0.59$; BG: 95% high school diploma, 5% university diploma; CG: 78.9% high school diploma, 15.8% university diploma), and body mass index (BMI; $t(37) = -0.32$, $p = 0.76$; BG: 22.0 ± 3.2, CG: 22.4 ± 5.0).

Prior to the experiment, we asked the participants to rate their general preference/liking of salty, sweet, sour and bitter food in their everyday diet on nine-point Likert scales (1 = 'not at all', 9 = 'very much'). There were no group differences (GROUP: $F(1,37) = 3.16$, $p = 0.08$; GROUP x FOOD PREFERENCE: $F(3,111) = 1.41$, $p = 0.24$). Participants of both groups preferred salty and sweet food over sour food, which in turn they liked better than bitter food (FOOD PREFERENCE: $F(3,311) = 113.03$, $p < 0.001$, $\eta 2p = 0.75$; salty: 7.72 ± 1.32; sweet: 7.56 ± 1.76; sour: 5.87 ± 2.00; bitter: 1.97 ± 1.37).

Furthermore, the participants reported comparable disgust proneness. Both groups did not differ in their mean scores on the Questionnaire for the Assessment of Disgust Proneness (QADP; Schienle, Walter, Bertram, Stark, Rudolf, & Vaitl, 2002; BG: 1.97, ±0.45; CG: 2.05 ± 0.35).

Exclusion criteria consisted of somatic disease, mental disorders (eating disorders, depression), medication and vegetarian diet. The information had been obtained by a board-certified clinical psychologist. In addition, the participants had answered a medical checklist developed by the authors. The subjects received course credit for their participation. They were carefully instructed and gave written informed consent. The study had been approved by the local ethics committee. The sample had been restricted to women because they report higher disgust proneness than men (Schienle et al., 2002).

2.2. Stimuli and design

2.2.1. Fluids

The subjects tasted either wormwood tea or water. The participants took a sip of exactly 20 ml and kept in their mouth for 30 s until they were allowed to spit it out. A pilot study had indicated that the bitter taste sensation continued for at least 10 min after the wormwood tea was removed from the mouth. Thus, there was prolonged aftertaste (the fluids were only tasted once prior to the picture presentation). The aftertaste was rated according to perceived bitterness, intensity and experienced disgust on 9-point Likert scales (9: maximum value). The tea was made with 2 tsp of dried herbal powder per 100 ml of water. The tea steeped for exactly 7 min and then cooled down to room temperature. Wormwood mainly contains absinthin. Its bitterness value is defined as at least 10,000 (ÖAB, Bisset, 1994).

2.2.2. Visual stimuli

The participants were exposed to a total of 90 different pictures taken from the Food Pics Database (Blechert, Meule, Busch, & Ohla, 2014). The images showed high-caloric sweets (e.g., cakes, ice-cream, cookies), high-caloric meat dishes (e.g. burgers, steaks, pizza), and low-caloric vegetarian food (e.g., salads, boiled vegetables). Each category consisted of 30 pictures. The two high-caloric categories had been matched for the amount of calories per 100 g. The pictures were shown in random order for 1500 ms each and were preceded by a fixation cross (500–1000 ms). Five pictures per category (random selection prior to the experiment) had to be evaluated by the participants according to valence, arousal and appetite on 9-point Likert scales (1 = negative valence, low arousal, low appetite).

2.3. Procedure

After an online screening (questionnaire, medical checklist), participants were invited to the EEG testing. At the laboratory, they were randomly assigned to one of the two fluid conditions. The participants arrived at the University after a fast of 4 h. Written informed consent was obtained and height and weight were measured. After the EEG electrode placement (approximately 20 min), the participants were carefully instructed and completed a test trial (~10 min). Then, the fluids were tasted, spat out and the