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Verbal labels selectively bias brain responses to high-energy foods

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ABSTRACT

The influence of external factors on food preferences and choices is poorly understood. Knowing which and how food-external cues impact the sensory processing and cognitive valuation of food would provide a strong benefit toward a more integrative understanding of food intake behavior and potential means of interfering with deviant eating patterns to avoid detrimental health consequences for individuals in the long run. We investigated whether written labels with positive and negative (as opposed to 'neutral') valence differentially modulate the spatio-temporal brain dynamics in response to the subsequent viewing of high- and low-energetic food images. Electrical neuroimaging analyses were applied to visual evoked potentials (VEPs) from 20 normal-weight participants. VEPs and source estimations in response to high- and low- energy foods were differentially affected by the valence of preceding word labels over the ~260–300 ms post-stimulus period. These effects were only observed when high-energy foods were preceded by labels with positive valence. Neural sources in occipital as well as posterior, frontal, insular and cingulate regions were down-regulated. These findings favor cognitive–affective influences especially on the visual responses to high-energetic food cues, potentially indicating decreases in cognitive control and goal-adaptive behavior. Inverse correlations between insular activity and effectiveness in food classification further indicate that this down-regulation directly impacts food-related behavior.

Introduction

Before eating, foods are valued according to their visual, olfactory and expected reward properties and ultimately selected for ingestion or not. For instance, the energy content (viz. calories or fat) of visually presented foods is automatically processed in the brain through a network encompassing visual as well as reward- and choice-related areas (Killgore et al., 2003; Stoeckel et al., 2008; Toepel et al., 2009). Yet, food-external information can influence food preferences and choices and related brain response patterns as well, e.g. price tags (Knutson et al., 2007; Plassmann et al., 2008) and affect conveyed by faces (Winkielman et al., 2005). Verbal labels also substantially impact food sensation and hedonics (de Araujo et al., 2005; Grabenhorst et al., 2008; Linder et al., 2010; Ng et al., 2011). However, this interplay varies not only as a function of the emotional valence of a label (e.g. whether the label conveys positive or negative information), but also on the underlying sensory properties of a stimulus (i.e. whether an aversive or appetitive olfactory, gustatory or visual cue is perceived).

In a functional magnetic resonance imaging (fMRI) study, Ng et al. (2011) compared brain activation patterns between normal- and over-weight women while they received (or anticipated the receipt of) identical milkshake drinks that were differentially labeled as 'low-fat' or 'regular' (high-fat). When the identical sensory stimulation was accompanied by the high-fat as opposed to the low-fat label, over-weight women showed higher activity in ventral prefrontal somatosensory and reward-related brain regions (in contrast to normal-weight women). The authors suggested that these findings might indicate a 'perceived' lack of reward in overweight that is likely to be compensated by increased food intake. Another fMRI study investigated the influence of bio-organic labeling on visual food valuation and choices (Linder et al., 2010), i.e. employing a label that conveys positive information. For this purpose, study participants were presented with a range of food items that were accompanied either by a bio-organic label or by a rather neutral label. The study showed elevated activation in cortical (dorsolateral prefrontal cortex) and subcortical (striatum) brain regions when foods with the positive as opposed to the neutral label were perceived indicating the impact of labeling on food-related reward valuation and choice-making.

Furthermore, Grabenhorst et al. (2008) showed that the pleasantness of a flavor stimulus could be increased by a positive as compared with a neutral label; this modulation being accompanied by increased

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activation in the medial orbitofrontal cortex. Similarly, a study by de Araujo et al. (2005) indicated that the unpleasantness of an aversive odor could be decreased by a positive descriptor, as compared with a negative descriptor, with concomitant increases of neural activity in the anterior cingulate and medial orbitofrontal cortices. A similar effect, that is the reduction of perceived unpleasantness, was also shown in the study by Nitschke et al. (2006). They primed the delivery of an aversive bitter taste with a negative label and found that the negative label reduced the perceived unpleasantness of the taste. This behavioral effect was accompanied by reduced activity in the insula.

Taken together, several studies indicate that verbal–emotional labeling impacts the perception and valuation of food cues. Hemodynamic imaging studies have furthermore shown that behavioral modulations like altered pleasantness ratings induced by labeling are associated with changes in neural activation, e.g. in ventral prefrontal brain regions. Yet, evidence regarding the time course of labeling-induced modulations in food perception is still lacking. However, determining whether early signs of food discrimination are already influenced by food-external information might prove to be helpful to interfere with food valuation processes in the context of future therapeutic approaches to eating disorders.

One study has so far investigated the association of event-related potentials (ERPs) and pleasantness ratings. Identical gustatory stimuli were preceded by either a high-fat or low-fat pictorial food cue (Ohla et al., 2012). The identical gustatory incentives were rated as more pleasant when preceded by the image of a high-fat as opposed to a low-fat food. The pleasantness ratings correlated positively with source activity in the ventral prefrontal cortex at ~180 ms after taste onset and correlated negatively with insular activations observed at ~350 ms. These findings highlight that food perception and valuation processes as well as the accompanying brain activity in reward-related brain areas are implicitly modulated by external cues at early latencies.

Here, we investigated the influence of emotional labeling on the spatio-temporal brain dynamics accompanying the visual categorization of high- and low-energetic foods (in terms of fat content; Toepel et al., 2009). For this purpose, the viewing of each food image was preceded by the viewing of a word label with positive, negative or neutral emotional valence. We recorded VEPs while normal-weighted participants viewed the label–food combinations. As we could previously show that energetic properties impact the spatio-temporal brain dynamics of visual food discrimination (Toepel et al., 2009) and several studies revealed that labeling can influence the sensory processing and valuation of foods, we assumed that emotional labeling would differentially alter the responses to high- and low-energy foods.

Materials and methods

Stimuli: emotional labels

We collected >100 French attributes related to daily food intake from dictionaries and the internet and asked 40 participants (17 males; mean ± s.e.m. age 26 ± 0.67 yrs.) to judge them for emotional valence on a 1–7 point Likert scale (1 = very negative, 7 = very positive). Among these attributes, 75 were judged as positive (mean ± s.e.m. rating = 6.27 ± 0.15), neutral (4.03 ± 0.21) and negative (1.75 ± 0.15), i.e. 25 for each emotional label. All participants indicated in addition that they were well familiar with the food attributes.

Further, 18 different volunteers (10 males; mean ± s.e.m. age = 25.2 ± 0.59 yrs) judged the final attribute selection on the 1–9 point Self-Assessment-Manikin scale (SAM; Bradley and Lang, 1994) for valence and arousal. Thereby, the attributes previously classified as negative were judged more negative (mean = 2.12, s.e.m. ± 0.30) in valence than the neutral (mean = 3.88, s.e.m. ± 0.16; $t_{24} = 4.97$, $p \leq 0.001$) and the positive labels (mean = 5.63, s.e.m. ± 0.37; $t_{24} = 9.51$, $p \leq 0.001$). The positive labels were accordingly judged as more positive in valence than neutral labels ($t_{24} = 4.62$, $p \leq 0.001$). In terms of arousal measures, the negative (mean = 4.59, s.e.m. ± 0.20; $t_{24} = 2.61$, $p \leq 0.001$) and positive (mean = 4.35, s.e.m. ± 0.16; $t_{24} = 5.07$, $p \leq 0.001$) labels were judged as more arousing than the neutral ones (mean = 3.28, s.e.m. ± 0.12). Arousal judgments for the negative vs. positive labels did not differ. Examples of labels with positive valence were “appétissant” (appetizing), “sain” (healthy) and “frais” (fresh). Labels with negative valence were e.g. “avarié” (decayed), “dégoûtant” (disgusting) and “toxique” (toxic). Neutral valence label were e.g. “chauffé” (heated), “mou” (soft) and “coupé” (cut).

Stimuli: food images

Fifty high-energy and 50 low-energy food images (by means of fat content; cf. Toepel et al., 2009) were presented to 24 participants (12 female; mean ± s.e.m. age = 27.7 ± 1.32 yrs; mean ± s.e.m. BMI = 22.13 ± 0.45). The low-level visual features of all food images (i.e. luminosity), and between food image classes (i.e. spatial frequencies) had been adapted (Knebel et al., 2008). All photographs measured 300 × 300 pixels, which corresponded to ~6° visual angle on the computer monitor and were taken using an identical background from an identical top-view angle. Participants were asked to judge the food images on a 1–9 point SAM scale (Bradley and Lang, 1994) for valence and arousal. In terms of valence ratings, high-energy foods (mean ± s.e.m. = 5.19 ± 0.10) and low-energy foods (5.26 ± 0.11) did not differ significantly ($t_{49} \leq 1$). Also, there were no significant differences obtained in the arousal ratings between high-energy foods (4.08 ± 0.11) and low-energy foods (3.89 ± 0.11).

Participants in the EEG study

Twenty (11 female) normal-weighted volunteers, aged 18–32 yrs (mean ± s.e.m. = 24.1 ± 0.97 yrs; mean BMI ± s.e.m. = 22.07 ± 0.59), participated in the study. Nineteen of these participants were right-handed, and one was ambidextrous according to the Edinburgh Handedness Inventory (Oldfield, 1971). None of the participants had current or prior neurological or psychiatric illnesses or self-reported eating disorders. All participants had normal or corrected-to-normal vision. All of the EEG recording sessions started between 13:00 and 14:00 h to control for circadian modulations of hunger. Further, participants were instructed (and also themselves reported) to have eaten lunch before the recording sessions. All participants provided written, informed consent to the procedures, which were approved by the Ethics Committee of the Faculty of Biology and Medicine of the University of Lausanne and the Vaudois University Hospital Center (CHUV).

Procedure of the EEG study

Participants completed 600 trials via a 21″ CRT monitor that they viewed within an electrically shielded and sound attenuated booth. Each trial started with a central fixation cross, followed by the visual presentation of either an emotionally positive, negative or neutral food label for 500 ms. Following a variable inter-stimulus-interval (ISI) of 200–500 ms, participants were presented with either an image of an energy-dense high-fat food or an energy-sparse low-fat food for 500 ms in pseudo-randomized order (Fig. 1a). Subjects were asked to indicate by button-press on a response box using the index finger whether they thought that the preceding food item had depicted a food that is high or low in fat content. Responses were allowed during the presentation of the food image and 500 ms after image offset. This behavioral task served to drive participants' attention away from the verbal label for which no task instruction was given. Stimulus presentation and response recordings were controlled by E-Prime (Psychology Software Tools Inc., Pittsburgh, USA; www.pstnet.com/eprime). Emotional labels and food images were combined in a way that no food image was coupled more than once with the same verbal attribute.