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Food processing and emotion regulation in vegetarians and omnivores: An event-related potential investigation

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ABSTRACT

The present study investigated cognitive reappraisal during exposure to vegetarian and nonvegetarian food cues in food-deprived vegetarian and omnivore participants. In particular, we were interested in clarifying the motivational meaning of the foods that vegetarians avoid, as revealed by self-reported food craving, valence, and arousal, as well as by ERP measures of neural processing during passive viewing and emotional regulation. Twenty-four vegetarians and twenty-one omnivores were instructed to either passively look at the pictures (Watch) or to change the appetitive value of the food (Increase or Decrease). In vegetarians, meat and fish dishes elicited lower desire to eat, pleasantness, and arousal during each condition as compared to both omnivores and vegetarian food. In contrast with the subjective data, no group differences were observed in any of the ERP measures, suggesting that similar neural processing of food-cues occurred in vegetarians and omnivores both during passive viewing and cognitive reappraisal. Concerning the late ERP effects during cognitive reappraisal, we found an enhancement of the P300 and LPP amplitudes during the Increase and the Decrease as compared to the Watch condition and a reduction of the SW amplitude in the Decrease as compared to Watch condition. These results suggest that in a food deprivation condition it is difficult to reduce the appetitive value of food stimuli, as this cognitive strategy appears to require greater effort and a longer time to be implemented with respect to up-regulation. Overall, our findings suggest that, in vegetarians, aversion towards nonvegetarian food prevails at the subjective level and is consistent with their personal beliefs. In contrast, at the neural level, the intrinsic motivational salience of this type of food is preserved.

1. Introduction

In everyday life, especially in Western societies, food is everywhere. We are exposed to food stimuli in supermarkets, groceries, and restaurants and also on the streets, while watching television, or surfing the internet. In these situations, food is always depicted in the most appetizing manner. From a bio-evolutionary point of view, our attentional system helps people to detect food in the environment because this is important for survival (Toepel, Knebel, Hudry, le Coutre, & Murray, 2009). In a world where people have access to any kind of food, however, it becomes crucial to investigate how people respond to different types of food and how they regulate food intake.

Studies have long investigated food cue reactivity using event-related potentials (ERPs) thanks to their high temporal resolution that allows researchers to investigate different stages of stimulus processing. Although early ERP components, such as N100 and N200, reflect the physical features of stimuli as well as early selective attention to relevant stimuli (Meule, Kubler, & Blechert, 2013; Olofsson, Nordin, Sequeira, & Polich, 2008), later components are indices of maintained attention, memory storage, or meaning evaluation (Hajcak; Macnamara, & Olvet, 2010; Schupp, Flaisch, Stockburger, & Junghofer, 2006). In particular, the P300 and the Late Positive Potential (LPP) are positive voltage deflections distributed across the scalp, where maximum amplitudes are usually found at parietal and centroparietal sites (Schupp et al., 2000). The latency of the P300 goes from 300 ms to 500 ms after stimulus onset, whereas the LPP starts 500 ms after stimulus and can last up to 6000 ms (Cuthbert, Schupp, Bradley, Birbaumer, & Lang, 2000). These ERP components can be interpreted as indices of the stimulus's emotional meaning (Olofsson et al., 2008) because their amplitudes are larger for pleasant and unpleasant stimuli compared to neutral stimuli, especially for highly arousing stimuli (Cuthbert et al., 2000; Leite et al., 2012; Palomba, Angrilli, & Mini, 1997; Schupp et al., 2000). Specifically, the LPP reflects the motivated attention that an evolutionary relevant stimulus automatically attracts

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(Littel, Euser, Munafò, & Franken, 2012).

As food can be considered a highly appetitive and arousing stimulus, especially during deprivation, research on food processing focused more on late ERPs. Food pictures were found to elicit larger LPPs compared to neutral stimuli (Nijs, Franken, & Muris, 2008), especially when participants were hungry compared to when they were satiated (Nijs, Muris, Euser, & Frenken, 2010; Stockburger, Schmalzle, Flaisch, Bublatzky, & Schupp, 2009). Moreover, Meule, Kubler, & Blechert (2013) found that the LPP elicited by high-calorie food was larger than the LPP elicited by low-calorie food.

In a world where people have access to every kind of food, the nutritional needs of the organism can be overshadowed by other factors, such as personal taste and personal beliefs (Martins & Pliner, 2005; Rozin, Markwith, & Stoess, 1997). For instance, some people could develop a strong dislike and even disgust for animal products due to moral and/or health reasons (Allen, Wilson, Ng, & Dunne, 2000; Amato & Partridge, 1989; Kenyon & Barker, 1998). In this sense, vegetarianism is an example of a hedonic shift from liking to disliking or disgust toward a particular category of food items, specifically meat and fish products, and a common definition of a vegetarian is “someone who does not eat red meat, poultry, or fish” (Ruby, 2012).

The literature about neural food processing in vegetarian individuals is very limited. An investigation by Stockburger, Renner, Weike, Hamm, and Schupp (2009) showed that meat stimuli elicited higher amplitudes of the LPP in vegetarians compared to omnivores. This effect was specific for meat stimuli, as it was not apparent for stimuli depicting vegetable dishes. The authors hypothesized that the processing of food stimuli is related to individuals' biological needs and to the stimuli's emotional salience associated with food choices and the aversion towards a particular category of food, but they did not state which aspect is predominant in vegetarians nor they measured participants' subjective affective experience. Higher LPP for meat products in vegetarians could reflect either the allocation of attentional resources for a survival-relevant stimulus, or the development of acquired salience as an aversive stimulus. Meat is important for survival as the source of calories and nutrients that the body needs. However, for vegetarians, as compared to omnivores, these foods might also acquire affective salience due the aversion elicited.

A recent psychophysiological study (Anderson, Wormwood, Barrett, & Quigley, 2018) investigated the self-reported affective experience of vegetarians and omnivores during exposure to different food cues, while recording peripheral physiological indices (e.g., skin conductance level, facial EMG over the corrugator supercilii and levator labii facial muscle regions, and heart period). They found that vegetarians rated meat food as less appetizing than omnivores and reported feelings of disgust and sadness while exposed to meat food. This pattern of self-reported results was specific to meat food, as no difference between vegetarians and omnivores emerged for nonmeat food (e.g., vegetable meals and sweet foods). However, the two groups did not differ in the cardiac and facial EMG responses, which were comparable for every type of food picture. In terms of electrodermal activity, vegetarians showed overall higher levels of activation compared to omnivores, but this effect was not specific for meat food. The authors hypothesized that the physiological responses of vegetarians to meat stimuli are automatically reduced in order to be consistent with their diet and belief system, thus leading to more negative self-reported emotions (Anderson et al., 2018). According to the authors, this may protect vegetarians from giving in to the temptation of meat. The absence of effects on the facial EMG denotes that the exposure to meat stimuli did not provoke an implicit aversiveness in vegetarians. Thus, the subjective aversive response of vegetarians toward meat seems to be cognitively mediated by their moral beliefs.

According to some authors, the LPP can be also interpreted as a neural marker of emotion regulation (for a review, see Hajcak et al., 2010). Emotion regulation has been defined by Gross (1998) as “the processes by which individuals influence which emotions they have, when they have them, and how they experience and express these emotions. Emotion regulatory processes may be automatic or controlled, conscious or unconscious.” In the literature, the majority of the ERP studies on emotion regulation have focused on visual aversive stimuli (e.g., human threats, animal threats, and mutilations). The reduction of the emotional impact of the stimuli in these studies, especially by using cognitive reappraisal, a strategy involving the reinterpretation of the meaning of the emotional stimulus (Ray, McRae, Ochsner, & Gross, 2010), is associated with a decrease in the LPP amplitude (Hajcak & Nieuwenhuis, 2006; Moser, Hajcak, Bukay, & Simons, 2006; Moser, Krompinger, Dietz, & Simons, 2009). Investigations concerning the reappraisal of positive stimuli are rare. Krompinger, Moser, and Simons (2008) found that participants successfully decreased the experienced positive affect in front of positive stimuli (e. g., children and animals, triumphant sports moments, and nudity and eroticism), as indexed by a reduction of the LPP amplitude, but they failed in increasing it.

While the research about food processing concentrated mostly on passive viewing of the stimuli, very few studies investigated the neural correlates of the regulation of motivational and emotional aspects involved in food processing mechanisms. In an ERP study by Sarlo, Ubel, Leutgeb, & Schienle (2013), participants were exposed to food stimuli after an overnight fast. They were asked to passively view pictures and to increase or decrease the positive emotional response to them. The results showed that the amplitudes of P300 and LPP were larger during the Increase condition than during passive viewing, whereas the Decrease condition did not result in any amplitude reduction. This study demonstrated that the appetitive value of food is easy to enhance via emotion regulation, as indexed by the modulation of the LPP amplitude, but it is very difficult to reduce.

To the best of our knowledge, there are no studies that have investigated emotion regulation processes toward food in vegetarian individuals. As the number of vegetarians is constantly growing (e.g., Ruby, 2012), people who decide or need to shift to vegetarianism because of health or medical issues may benefit from the use of cognitive strategies, such as reappraisal, to avoid non-vegetarian food, which could remain very attractive for them. The use of emotion regulation paradigms could clarify the motivational meaning of the foods that vegetarians decided to avoid (meat and fish). On these bases, the present study aimed to investigate the characteristics of neural processing and cognitive reappraisal for food stimuli in vegetarians, in particular for those foods that they decided to avoid. Two groups (vegetarians and omnivores) were exposed to vegetarian and nonvegetarian food pictures and instructed to passively look (Watch) at the pictures or to regulate (Increase and Decrease) the appetitive value of the stimuli while recording the EEG and measuring self-reported affective experience and desire to eat. We hypothesized that if aversion towards nonvegetarian food prevails over its intrinsic properties to promote survival, vegetarians would easily dampen the appetitive value of this food and would have difficulties in increasing its appetitive value, as assessed by the modulation of self-reported affective responses and ERP P300/LPP amplitudes. In contrast, if the motivational salience related to biological needs is predominant, vegetarians would still be very attracted to nonvegetarian food, thus showing difficulties in decreasing, but not in increasing, its appetitive value.

2. Method

2.1. Participants

Forty-five participants (20 M) aged between 19 and 33 years took part in this study. They were divided into two groups based on their food preferences: vegetarians (N = 24, 11 M; mean age = 23.46, DS = 3.68) for at least one year and omnivores (N = 21, 9 M; mean age = 23.62, DS = 1.40). Mean body mass indexes (BMI) were 20.68 kg/m^2 (DS = 2.11, range = 17.48–27.1) and 21.84 kg/m^2

(DS = 3.53, range = 18.39–32.65), respectively. The two groups were comparable for BMI (t (43) = 1.36, p = .18). The vegetarian group included one overweight participant (0.4%) and the omnivore group two overweight participants (0.9%). The ratio of overweight/normal-weight participants was comparable in the two groups ($\chi_2(1)$ = .52, p = .47).

Vegetarians did not eat either meat or fish food. The majority of the vegetarian participants (13 out of 24, 54%) reported exclusively moral reasons (related to animal welfare and environmental sustainability) for choosing a vegetarian diet, 7 participants reported both moral and health reasons (29%), and the remaining 4 participants (17%) reported different combinations of moral, health, and meat-taste aversion motives.

Participants were recruited via social network advertisements and campus announcements. Exclusion criteria were substance abuse or addiction, clinically relevant depression, eating disorders, neurological disorders, and the current use of any medication.

The present study was carried out with the adequate understanding and written consent of the participants in accordance with the Declaration of Helsinki. The study was approved by the Ethics Committee of the Departments of Psychology, University of Padova.

2.2. Stimuli and design

A total of 56 pictures were used, taken partly from the *Open Library Affective Food* (Miccoli, Delgado, Rodriguez-Ruiz, Guerra, & Garcia-Màrmol, 2014) and partly from the Internet. The pictures were divided into two blocks: 28 pictures depicted vegetarian food (i.e., vegetables and fruits, *Veg Food*) and twenty-eight pictures showed nonvegetarian food (i.e., meat and fish dishes, *Noveg Food*). We did not include food such as eggs and milk products because the Vegetarian sample included vegans; in addition we excluded food that might have been mistaken for another (e.g., tofu for cheese, seitan for meat).

Each block of pictures was shown in counterbalanced order within each condition (Watch, Increase, and Decrease) and participants received standardized instructions. In the Watch condition, participants passively viewed food pictures with the instructions: “Now we ask you to look at each picture and allow yourself to experience/feel every emotional response it might elicit.” The Watch condition was always the first one presented, followed by the Increase and Decrease conditions in counterbalanced order. In the Increase condition, participants received these instructions for the emotion regulation task: “Please reappraise each picture so that the content is more appetizing for you. Imagine that the food tastes delicious and that you are allowed to eat it later on.” In the Decrease condition, participants read: “Please reappraise each picture so that the content is less appetizing for you. Imagine that the depicted food is not real, it is a plastic model.” In each block, the pictures were presented in a random order. Each block was preceded by a fixation cross (800–2200 ms, random), the keyword of the condition (Watch, Increase, Decrease; 5 s) and the relative instructions (15 s). Each picture was presented for 4 s. Following the presentation of each picture block, participants were asked to rate their emotional experience during the picture viewing using the Self-Assessment Manikin (SAM; Lang, Bradley, & Cuthbert, 2008) with the two classic 9-point scales of the valence (pleasantness/unpleasantness) and arousal (activation/calm) dimensions and the 9-point scale of “food craving/desire to eat” proposed by Miccoli et al. (2014). Only in the Increase and Decrease conditions were participants also asked to evaluate their effort during the emotion regulation reappraisal task on a 9-point Likert scale.

2.3. Procedure

Participants arrived at the psychophysiology laboratory in the morning after an overnight fast. Prior to the experiment, they were only allowed to drink water, and they were explicitly asked whether they had adhered to this protocol. Then participants were introduced to the EEG procedure and asked to sign an informed consent. Their body mass index (BMI) was also measured. As an initial screening question, each Vegetarian participant was asked about his/her motivations for adopting a vegetarian diet.

The experiment took place in a dimly lit, sound-attenuated room and participants were seated 1.2 m from the monitor on which the pictures were presented through the E-Prime software. Before beginning the experiment, participants received a training session. They were presented with pictures similar to the ones later used in the experiment, and they received standardized instructions. Then they were asked to practice reappraisal via self-instruction. Participants did not receive monetary compensation, but they were offered a free breakfast at the end of the experiment.

2.4. Electrophysiological recordings and data analyses

The electroencephalogram (EEG) was recorded from 11 sites (F3, Fz, F4, C3, Cz, C4, P3, Pz, P4, T5, and T6) using an EEG cap (Electro-Cap International, Inc., Ohio) and a V-Amp 16 system (Brain Products, Gilching, Germany). Four external electrodes were used for bipolar recording of the horizontal and vertical electrooculogram (EOG), and two electrodes were placed on the mastoids (A1 and A2). All EEG sites were referenced online to A1 and digitally re-referenced off-line to linked mastoids. All electrode impedances were kept below 5 kΩ. The EEG and EOG signals were band-pass filtered (0.053–70 Hz) and digitized at 500 Hz.

Independent component analysis (ICA) was computed on all EEG channels in order to correct for EOG artifacts. EEG data were segmented into 1700-ms epochs from 200 ms before to 1500 ms after the stimulus onset. All epochs were refiltered off-line with a low-pass filter set to 30 Hz and then baseline-corrected against the mean voltage during the 200-ms prestimulus period. All epochs were visually scored for residual artifacts, and each portion of data containing artifacts greater than ± 70 μV in any channel was rejected for all the recorded channels prior to further analysis. Artifact-free epochs were separately averaged for each subject in each experimental condition. The mean numbers of trials after preprocessing were: 26.49 for the Watch-Veg condition; 26.2 for the Watch-Noveg condition; 25.51 for the Increase-Veg condition; 25.85 for the Increase-Noveg condition, 25.64 for the Decrease-Veg condition, 26.16 for the Decrease-Noveg condition.

Based on a visual inspection of grand average ERP waveforms, mean amplitudes were computed in the 280–400 ms time window for the P300 and in the 500–600 ms time window for the LPP. As exploratory analysis, the mean amplitude was computed in the 130–230 ms (N200) and 800–1400 ms (Slow Wave, SW) time windows (Figs. 1 and 2).

Repeated-measures analyses of variance (ANOVAs), with *Group* (vegetarians and omnivores) as a between-subject factor and *Area* (Frontal F, Central C, Parietal P), *Laterality* (Left, Midline, Right), *Condition* (Watch, Increase, Decrease) and *Food* (Veg, Noveg) as within-subject factors, were conducted on the mean amplitudes of N200, P300, LPP and SW.

Mean subjective ratings of food craving, valence, arousal, and effort were submitted to separate repeated-measures ANOVAs with *Group* as a between-subject factor, and *Condition* and *Food* as within-subject factors. For experienced effort, the *Condition* factor had only two levels (Increase and Decrease).

Tukey HSD post-hoc tests were employed to further examine significant effects (using a $p < .05$ criterion for significance).

Lastly, for each group, exploratory Pearson's correlations were performed between BMI and both ERP mean amplitudes and subjective mean ratings, and between ERP measures and subjective ratings. Moreover, for the Vegetarian sample, Pearson's correlations were performed between years of vegetarianism and both ERP mean amplitudes and subjective mean ratings. P-values for exploratory correlations were Bonferroni-corrected.

3. Results

3.1. ERP data

3.1.1. N200 (130-230 ms)

The ANOVA conducted on the N200 amplitude revealed significant *Food* (F (1,43) = 12.90, p < .001, η_p^2 = .23) and *Condition* (F (2,86) = 5.27, p < .01, η_p^2 = .11) main effects, respectively showing that the amplitude of the N200 was significantly larger for the Noveg than for the Veg food, and in the Watch as compared to the Increase and Decrease conditions (all ps < .05).

Moreover, significant *Area* (F (2,86) = 161.38, p < .0001, η_p^2 = .79) and *Laterality* (F (2,86) = 74.01, p < .0001, η_p^2 = .63) main effects were found. As specified by the *Area X Laterality* interaction (F (4,172) = 38.95, p < .0001, η_p^2 = .46), the N200 was larger in the frontal as compared to the central and parietal areas at each laterality (ps < .001). Moreover, in the frontal sites the N200 was significantly larger in the midline relative to the left site (p = .02); in the central sites the N200 was larger in the midline relative to the left and right electrodes (ps < .01); in the parietal sites the N200 was larger in the midline as compared to the left and right sites (ps < .01) and in the left as compared to the right electrode (p = .02).

The Group main effect and the interactions involving the Group factor were not significant (all ps > .18).

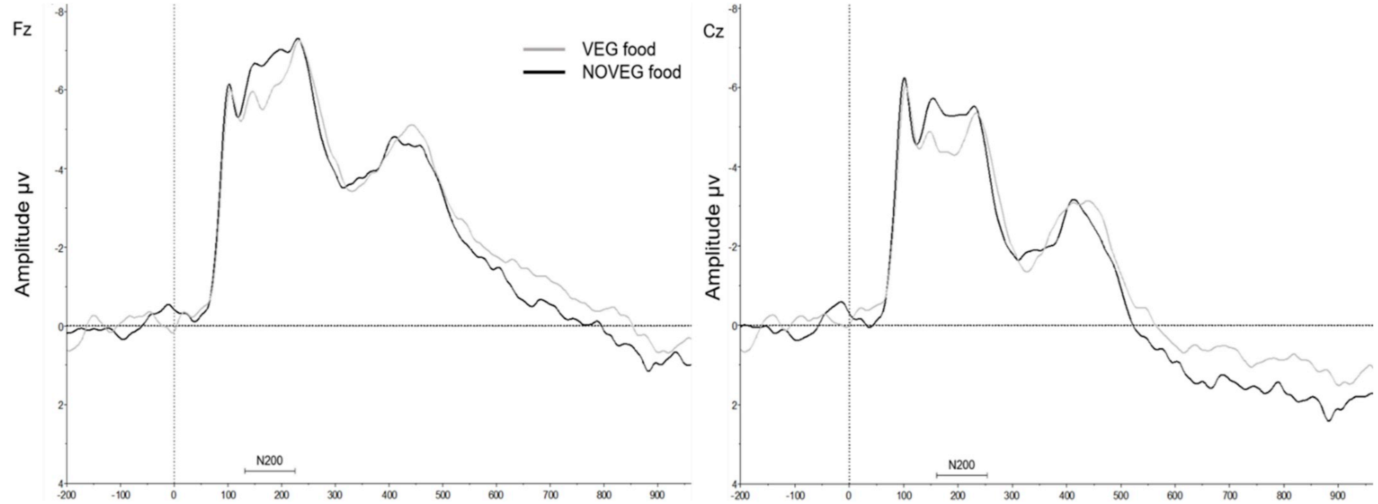

Fig. 1. Grand-average ERPs at the frontal and central midline electrodes for the two types of food stimuli.

3.1.2. P300 (280–400 ms)

The ANOVA revealed a significant main effect of *Condition* (F (2,86) = 6.21, p < .01, η_p^2 = .16). Post-hoc tests showed that the P300 was larger in the Increase and Decrease conditions as compared to the Watch condition (ps < .02).

The *Area* (F (2,86) = 167.61, p < .0001, η_p^2 = .80) and *Laterality* (F (2,86) = 57.86, p < .0001, η_p^2 = .57) main effects were significant. As specified by the *Area X Laterality* interaction (F (4,172) = 24.84, p < .0001, η_p^2 = .37), the P300 amplitude was larger in the parietal as compared to the central and frontal areas at each laterality (ps < .0001), and in the right site as compared to the midline and the left sites (ps < .0001) in the parietal but not in the central and frontal areas, where the amplitude was smaller in the midline than in the left and the right hemispheres (ps < . 05) and the difference between the left and the right hemispheres was not significant (ps > .20).

The *Area X Laterality X Food* (F (4,172) = 2.92, p < .05, η_p^2 = .06) was significant, however post-hoc tests did not show differences involving food types (ps > .09). Moreover, the *Area X Laterality X Group* (F (4,172) = 2.44, p < .05, η_p^2 = .05) was significant, but no differences between groups emerged at the post-hoc tests (ps > .99).

The Group main effect and the other interactions involving the Group factor were not significant (all ps > .41).

3.1.3. Late Positive Potential (500–600 ms)

The ANOVA conducted on LPP amplitudes in the 500–600 ms time window revealed a significant main effect of *Condition* (F (2,86) = 12.13, p < .0001, η_p^2 = .22). As specified by the significant *Area X Condition* interaction (F (4,172) = 2.62, p < .05, η_p^2 = .06), the LPP amplitude was larger during the Increase than in the Watch and Decrease conditions (ps < .05) in the parietal area, whilst in the central and frontal areas it was larger in the Increase and in the Decrease than in the Watch condition (ps < .0001), with no differences between the Increase and Decrease conditions (ps > .34).

The main effects of *Area* (F (2,86) = 186.29, p < .0001, η_p^2 = .81) and *Laterality* (F (2,86) = 34.88, p < .0001, η_p^2 = .45) were significant. As specified by the *Area X Laterality* interaction (F (4,172) = 12.76, p < .0001, η_p^2 = .23), the LPP amplitude was larger in the parietal as compared to the central and frontal areas at each laterality, and in the right sites as compared to the midline and left sites (all ps < .01) in all except the frontal area, where no difference emerged among lateralities (ps > .09).

The Group main effect and the interactions involving the Group factor were nonsignificant (all ps > .08).

3.1.4. Slow Wave (800–1400 ms)

The ANOVA revealed a significant main effect of *Condition* (F (2,86) = 6.67, p < .01, η_p^2 = .13), showing that the SW amplitude was significantly reduced during the Decrease than during the Watch condition (p < .01), with no difference between the Increase and the other conditions (ps > .17).

The main effects of *Area* (F (2,86) = 32.91, p < .0001, η_p^2 = .43) and *Laterality* (F (2,86) = 26.39, p < .0001, η_p^2 = .38) were significant. As specified by the *Area X Laterality* interaction (F (4,172) = 17.84, p < .0001, η_p^2 = .29), the SW amplitude was larger in the parietal than in the central and frontal areas (ps < . 0001), and in the central than in the frontal areas (ps < .0001) at each laterality except the midline sites, where comparable amplitudes were found in frontal and central areas (p = .21). Moreover, in the central area the SW amplitude was larger on the right than on the left and midline sites (ps < .01), in the parietal area on the right than on the midline site (p < .0001), whereas in the frontal area no laterality differences emerged (p > .79). Moreover, the *Area X Laterality X Group* (F (4,172) = 2.47, p < .05, η_p^2 = .05) was significant, but no differences between groups emerged at the post-hoc tests (ps > .99).

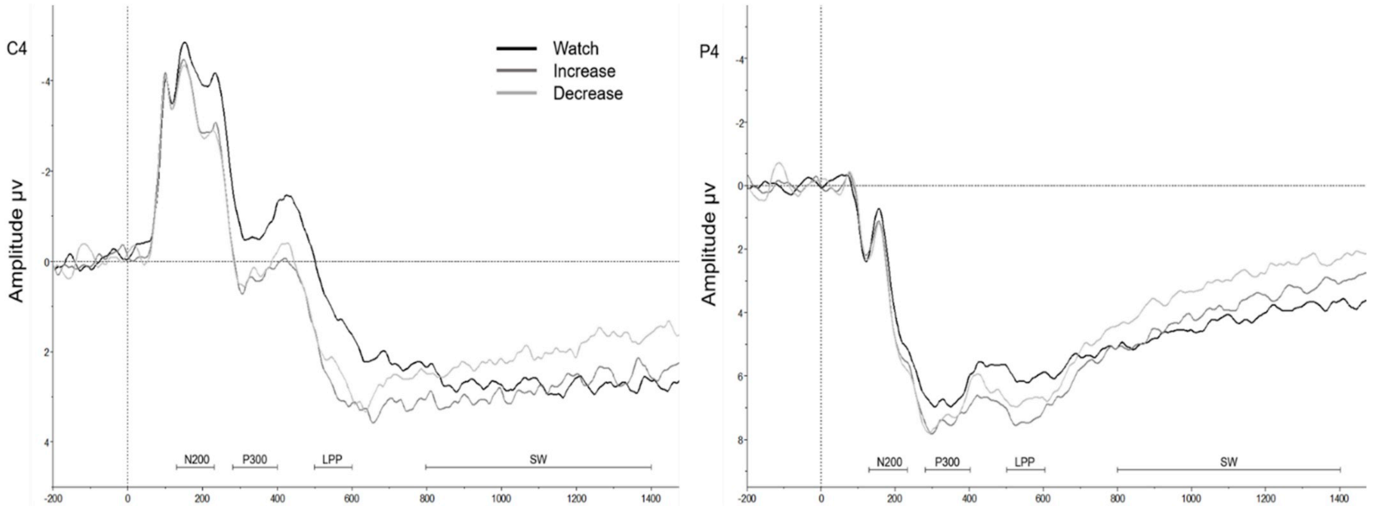

Fig. 2. Grand average ERPs at the central and parietal right electrodes for the three emotion regulation conditions (Watch, Increase, and Decrease).

The Group main effect and the other interactions involving the Group factor were not significant (all ps $>$ .27).

3.1.5. Subjective ratings

The mean subjective ratings as a function of group, food, and condition are displayed in Table 1.

3.1.6. Food craving

The ANOVA showed a significant *Condition* main effect (F (2,86) = 45.68, p $<$ .0001, η_p^2 = .52), with post-hoc tests revealing higher ratings in the Increase than in the Watch and Decrease conditions, and lower ratings in the Decrease as compared to the Watch condition (all ps $<$ .002).

The *Group* (F (1,43) = 11.61, p $<$ .002, η_p^2 = .21) and *Food* (F (1,43) = 11.62, p $<$ .002, η_p^2 = .21) main effects were significant. As specified by the *Group X Food* interaction (F (1,43) = 40.02, p $<$ .0001, η_p^2 = .48), vegetarians gave lower ratings to Noveg than to Veg food (p $<$ .0002), whereas no difference between food types was found for omnivores (p = .20). Moreover, Noveg food elicited significantly lower ratings in vegetarians than in omnivores (p $<$ .0002), whereas no difference between groups was found for Veg food (p = .83).

The significant *Group X Condition X Food* interaction (F (2,86) = 3.68, p $<$ .03, η_p^2 = .08) confirmed that vegetarians gave lower ratings than omnivores to Noveg food in each condition (all ps $<$ .05), while no differences between groups emerged for Veg food in any condition (all ps $>$ .99). Moreover, relative to the Watch condition, omnivores were able to significantly reduce the food craving for both types of food in the Decrease condition (ps $<$ .005), but not to increase it for either food type in the Increase condition (ps $>$ .24). Differently, vegetarians were able to significantly reduce the food craving for the Veg food in the Decrease condition (p $<$ .0006), but not to increase it in the Increase condition (p $>$ .99), whereas they were able to significantly increase the food craving for the Noveg food in the Increase condition (p $<$ .03), but not to decrease it in the Decrease condition (p $>$ .99).

3.1.7. Valence

The main effects of *Condition* (F (2,86) = 74.96, p $<$ .0001, η_p^2 = .64), *Food* (F (1,43) = 15.75, p $<$ .0003, η_p^2 = .27), and *Group* (F (1,43) = 18.56, p $<$ .0001, η_p^2 = .30) were significant. As specified by the significant *Group X Condition* interaction (F (2,86) = 10.06, p $<$ .0002, η_p^2 = .19), both groups gave lower valence ratings in the Decrease than in the Watch condition (ps $<$ .004), with no differences between the Watch and the Increase conditions (ps $>$ .41).

The significant *Group X Food* interaction (F (1,43) = 63.37, p $<$ .0001, η_p^2 = .60) showed that vegetarians gave significantly lower valence ratings to Noveg than to Veg food (p $<$ .0002), where the opposite was found for omnivores (p $<$ .05). Moreover, vegetarians gave higher ratings to Veg food (p $<$ .02) and lower ratings to Noveg food (p $<$ .0002) as compared to omnivores.

The significant *Group X Condition X Food* interaction (F (2,86) = 4.77, p $<$ .02, η_p^2 = .10) showed that, relative to the Watch condition, omnivores were able to significantly reduce the pleasantness

Table 1
Experienced food craving, valence, arousal, and effort (mean = M; standard deviations = SD) for each group during the three conditions.

Omnivores	Conditions					
	Watch Veg M (SD)	Watch Noveg M (SD)	Increase Veg M (SD)	Increase Noveg M (SD)	Decrease Veg M (SD)	Decrease Noveg M (SD)
Food craving	6.48 (1.50)	7.29 (1.55)	7.10 (1.04)	8.14 (0.96)	5.19 (1.66)	5.62 (2.16)
Valence	6.48 (1.33)	7.57 (1.33)	6.81 (1.25)	7.95 (0.97)	4.71 (1.49)	5.57 (1.78)
Arousal	5.43 (1.72)	6.62 (1.36)	6.10 (1.95)	7.24 (1.30)	4.43 (1.91)	5.33 (1.77)
Effort	–	–	4.95 (1.99)	3.29 (2.12)	5.33 (2.20)	6.43 (2.01)
Vegetarians	Watch Veg M (SD)	Watch Noveg M (SD)	Increase Veg M (SD)	Increase Noveg M (SD)	Decrease Veg M (SD)	Decrease Noveg M (SD)
Food craving	7.00 (1.59)	3.79 (2.08)	7.33 (1.66)	4.86 (2.46)	5.58 (2.00)	3.63 (2.46)
Valence	7.50 (0.98)	3.75 (1.70)	7.58 (1.02)	4.42 (1.82)	6.04 (1.43)	3.71 (1.37)
Arousal	6.29 (1.49)	5.29 (2.07)	6.67 (1.34)	5.83 (1.76)	5.58 (1.86)	4.79 (1.82)
Effort	–	–	2.65 (1.58)	5.58 (2.41)	5.79 (2.15)	4.46 (2.28)

experienced for both types of food in the Decrease condition ($ps < .0002$), but not to increase it for either food type in the Increase condition ($ps > .96$). Differently, vegetarians were able to significantly reduce the pleasantness of the Veg food in the Decrease condition ($p < .0002$), but not to increase it in the Increase condition ($p > .99$), whereas they were not able either to increase or decrease the pleasantness of the Noveg food in any condition ($ps > .34$).

3.1.8. Arousal

The ANOVA revealed a significant *Condition* main effect (F (2,86) = 20.38, $p < .0001$, $\eta_p^2 = .32$), showing that, as compared to the Watch condition, participants were overall able to effectively increase ($p < .05$) and decrease ($p < .0009$) the arousal experienced during the respective conditions of cognitive reappraisal.

The significant *Group X Food* interaction (F (1,43) = 25.18, $p < .0001$, $\eta_p^2 = .37$) showed that vegetarians gave significantly higher arousal ratings to Veg than to Noveg food ($p < .01$), where the opposite was found for omnivores ($p < .0035$). Moreover, vegetarians gave lower ratings to Noveg food ($p < .05$) as compared to omnivores, whereas no significant difference was found for Veg food ($p > .14$).

3.1.9. Effort

The ANOVA revealed a significant *Condition* main effect (F (1,43) = 28.03, $p < .0001$, $\eta_p^2 = .36$), showing that the effort perceived was overall higher during the Decrease than the Increase condition ($p < .0001$).

The significant *Group X Food* interaction (F (1,43) = 6.13, $p < .02$, $\eta_p^2 = .13$) showed that for vegetarians the effort was higher for Noveg than for Veg food ($p < .05$), while no differences between food types emerged for the omnivore group ($p > .81$), and no differences between groups were found ($ps > .26$).

As specified by the significant *Group X Condition X Food* interaction (F (1,43) = 45.83, $p < .0001$, $\eta_p^2 = .52$), vegetarians experienced more effort in increasing the appetitive value of Noveg than Veg food ($p < .0002$), and in decreasing than increasing the appetitive value of Veg food; omnivores reported comparable effort for the two types of food in every condition ($ps > .06$), and experienced more effort in decreasing than in increasing the appetitive value of Noveg food.

3.1.10. Correlational analyses

No statistically significant correlations emerged between mean subjective ratings and mean amplitudes of the ERP components in any condition when applying Bonferroni corrections. Moreover, BMI scores were not significantly correlated with ERP measures or subjective mean ratings after Bonferroni correction. Lastly, in the vegetarian sample, the years of vegetarianism did not significantly correlate with the ERP measures or mean subjective ratings when Bonferroni corrected.

4. Discussion

This present study was aimed at investigating cognitive reappraisal during exposure to vegetarian and nonvegetarian food cues in food-deprived vegetarian and omnivore participants. In particular, we were interested in clarifying the motivational meaning of the foods that vegetarians avoid (i.e., meat and fish), as revealed by self-reported food craving, valence, and arousal, as well as by ERP measures of neural processing during passive viewing and emotional regulation.

Our findings suggest that, in vegetarians, aversion towards nonvegetarian food prevails at the subjective level and is consistent with their personal beliefs. In contrast, at the neural level, the intrinsic motivational salience of this type of food is preserved.

A clear-cut difference emerged between vegetarians and omnivores in the pattern of self-report responses. In vegetarians, meat and fish dishes elicited lower desire to eat, lower pleasantness, and lower arousal during each condition (i.e., Watch, Increase, Decrease) as compared to both omnivores and vegetarian food. It is worth noting that vegetarians rated nonvegetarian food as clearly unpleasant (i.e., mean valence ratings < 4.5; see Lang et al., 2008). Taken together, these findings indicate that meat and fish were actually perceived as aversive by vegetarians at the subjective level, in line with previous research (Anderson et al., 2018).

Moreover, the results obtained during cognitive reappraisal showed that vegetarians were able to increase but not to decrease the food craving and pleasantness induced by nonvegetarian food, whereas omnivores showed the opposite pattern. These data might suggest that in vegetarians the biological relevance of meat and fish prevailed over the reported aversiveness. However, despite the higher effort reported for this food type during the Increase than the Decrease condition, subjective valence ratings failed to reach the pleasantness range (i.e., > 5.5; see Lang et al., 2008), suggesting that a genuine aversive motivation toward nonvegetarian food hindered the up-regulation process in vegetarians. On the other hand, the failure to down-regulate craving and valence ratings to nonvegetarian food could likely be due to a floor effect, as suggested by the already low scores provided during the Watch condition.

In marked contrast with the subjective data, no group differences were observed in any of the ERP measures, suggesting that similar neural processing of food-cues occurred in vegetarian and omnivore participants both during passive viewing and cognitive reappraisal.

The lack of modulation of LPP amplitudes by food preference or food type is at odds with what reported by Stockburger, Renner et al. (2009), who found larger amplitudes for meat food in vegetarians as compared to omnivores, and larger amplitudes for meat than vegetarian food in vegetarian participants. It is worth noting that the authors did not test food-deprived participants and that larger LPPs to food cues are typically obtained under food deprivation than under satiety (Stockburger, Schmälzle et al., 2009; Nijs, Muris, Euser, & Franken, 2010), indicating an overall higher motivational value of food stimuli. Therefore, the increased LPP amplitudes found by Stockburger, Renner et al. (2009) for meat in vegetarians might be due to the satiation level of participants that let their moral beliefs prevail over the stimulus intrinsic motivational salience. In our study, participants' state of hunger might have increased the relevance of nonvegetarian food for vegetarians and of vegetarian food for omnivores, thus canceling out any expected effect. Future research might test this interpretation by manipulating food deprivation and hunger levels.

Another important difference with Stockburger, Renner et al.'s (2009) study is that they employed only meat-based dishes as nonvegetarian food, whilst in our study pictures of fish food were also included, as our sample of vegetarians did not eat either fish or meat. However, differently from fish, meat has played a crucial role in human evolution and is still considered as a prototypical nutrient-dense food (Pereira & Vicente, 2013). Indeed, recent research (Buodo, Rumiati, Lotto, & Sarlo, 2019) has demonstrated that meat dishes draw sustained attentional resources throughout the late processing stages and are highly resistant to cultural influence as compared to other food-cues. Therefore, the presence of fish within nonvegetarian stimuli might have been a confound that overshadowed possible group differences in ERP measures.

Concerning the late ERP effects during cognitive reappraisal, we found an enhancement of the P300 and LPP amplitudes during the Increase as compared to the Watch condition, in line with the results of Sarlo, Übel, Leutgeb, and Schienle (2013). These effects indicate that the participants successfully augmented the appetitive value of the food stimuli independently from food type or their food preference. In contrast with previous studies using unpleasant (Moser et al., 2006) or pleasant (Krompinger et al., 2008) nonfood stimuli, the Decrease condition did not prompt lower LPP amplitudes, but similar (in the parietal areas) or even larger amplitudes (in the frontal and central areas) as compared to passive viewing. In the above studies, however, participants did not receive specific instructions about the strategy they might use to regulate the emotions elicited by the stimuli, and therefore there is the possibility that they diverted attention away from the stimuli. Differently, during the Decrease condition our participants received specific instructions to process the food depicted in each picture as if it was "not real, a plastic model", and thus we can hypothesize that the observed enhancement of the LPP was due to the deployment of attentional resources involved in the cognitive reappraisal process. This interpretation is consistent with the results obtained for the self-reported effort, which was overall higher during the Decrease than the Increase condition.

Moreover, the instructions to increase and decrease the appetitive value of the stimuli elicited larger P300 amplitudes relative to an instruction to passively view the pictures, possibly reflecting increased phasic attention to (what became) task-relevant stimuli (Sarlo et al., 2013; Weinberg, Hilgard, Bartholow, & Hajcak, 2012). Interestingly, the neural effects of a successful down-regulation emerged only quite late during the processing stream, i.e., in the 800-1400 ms time window, as indicated by the larger SW amplitude observed for the Decrease than the Watch condition.

Taken together, the results on the late ERP components suggest that in a food deprivation condition it is particularly difficult to reduce the appetitive value of food stimuli, as this cognitive strategy appears to require greater effort and a longer time to be implemented with respect to up-regulation.

As for the considered early ERP component, larger N200 amplitudes were observed for nonvegetarian than vegetarian food, indicating early automatic attention to relevant stimuli (Meule, Kübler, & Blechert, 2013; Olofsson et al., 2008). Indeed, nonvegetarian stimuli were composed of meat and fish food, which are more energetic and more protein-laden than fruits and vegetables. Therefore it is likely that, in a food-deprived condition, this kind of food becomes particularly important for survival and automatically attracts attention. This finding is in line with those reported by Toepel et al. (2009) using visual evoked potentials, who showed that our brain can rapidly discern food energetic value, ~ 165 ms after stimulus presentation.

In addition, we found larger N200 amplitudes in the Watch as compared to the Increase and Decrease conditions. This effect seems consistent with the overall larger late positivity found during the cognitive reappraisal tasks relative to passive viewing and suggests that cortical positivity was higher (i.e., negativity was lower) throughout the emotional regulation process, reflecting needs for attentional engagement.

In sum, a striking dissociation emerged between subjective and neural measures of food-cue processing and regulation, consistent with previous findings by Anderson et al. (2018). Vegetarian participants reported lower appetite, pleasantness, and arousal toward meat and fish food, as compared to omnivores and also relative to vegetarian food, whereas their neural activity highlighted the same intrinsic motivational salience for both food types, similarly to what observed in omnivores. Indeed, self-report measures are subject to deliberate cognitive processes, directly reflecting beliefs and attitudes, as well as acquired, individual preferences, rather than the implicit motivational significance of food (see Czyzewska & Graham, 2008). It is therefore possible that vegetarians' attitudes toward nonvegetarian food are cognitively mediated in order to automatically reduce the attractiveness of this kind of food.

Some limitations of the current study should be noted. There is a lack of homogeneity regarding BMIs values within the groups of omnivores and vegetarians, that included some overweight participants. Also, within the vegetarian sample there were different motivations (moral, taste-related, and health-related reasons) for shifting to a vegetarian diet. Moreover, one year of vegetarianism could not be sufficient to affect the neural responses to non-vegetarian food. Future studies may investigate how each specific motivation for shifting to a vegetarian diet influences the processing of visual food cues, and whether there is a time threshold in being vegetarian, after which the neural processing of non-vegetarian food changes. Lastly, the two food categories presented in our study were not matched for energy content, even if the vegetarian food category included pictures of cooked dishes in addition to raw foods. Future studies should take this issue into account.

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