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The role of associative learning in healthy and sustainable food evaluations: an event-related potential study

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Abstract

Individuals in industrialized societies frequently include processed foods in their diet. However, overconsumption of *heavily-processed* foods leads to imbalanced calorie intakes as well as negative health consequences and environmental impacts. In the present study, normal-weight healthy individuals were recruited in order to test whether associative learning (*Evaluative Conditioning*, EC) could strengthen the association between food-types (*minimally-processed* and *heavily-processed* foods) and concepts (e.g., *healthiness*), and whether these changes would be reflected at the implicit associations, at the explicit ratings and in behavioral choices. A semantic congruency task with Electroencephalography recordings was used to examine the neural signature of newly acquired food.

The accuracy after EC towards minimally-processed food (MP-food) in the SC task significantly increased, indicating strengthened associations between MP-food and the concept of healthiness through EC. At neural level, a more negative amplitude of the N400 waveform, which reflects semantic incongruency, was shown in response to MP-foods paired with the concept of unhealthiness in proximity of the dorsal lateral prefrontal cortex (DLPFC). This implied the possible role of the left DLPFC in changing food representations by integrating stimuli's features with existing food-relevant information. Finally, the N400 effect was modulated by individuals' *attentional impulsivity* as well as restrained eating behavior.

KEYWORDS: Eating behaviors, food choices, associative learning, electroencephalography, N400, impulsivity

1. Introduction

Human food intake is determined by homeostatic needs and reward-based behaviors (Berthoud, 2011; Lutter & Nestler, 2009). Eating without a need to restore an energy imbalance is particularly frequent in Western countries where foods and food-cues are overwhelmingly available (Alonso-Alonso et al., 2015). Our food choices have a considerable impact on our health and well-being. Due to industrialized and urbanized living styles, *processed food*, that is food that has been transformed by humans (see Foroni, Pergola, Argiris, & Rumiati, 2013; Foroni & Rumiati, 2017), is easily accessible while consumption of more natural food has decreased (McMichael, Powles, Butler, & Uauy, 2007). It is widely recognized that the overconsumption of *heavily-processed* food (HP-food; e.g., ready-to-eat frozen dinners, sweetened snacks) instead of *minimally-processed* food (MP-food; e.g., dried fruit, boiled vegetables) plays a role in the widespread of obesity and related chronic diseases (World Health Organization, 2003). Thus, understanding the neural mechanisms of food choices which lead to an imbalance between energy intake and expenditure and how to improve it becomes of paramount relevance (Wyatt, Winters, & Dubbert, 2006).

Processed food can be defined as food with any deliberate change before being eaten, ranging from *MP*- to *HP*-food (Duyff, 2017; Jones & Clemens, 2017). HP-food usually contains added sweeteners, saturated fats, artificial colors, high levels of sodium, and preservatives, whereas, MP-food, goes through less industrial process, resulting in reduced changes in the ingredients properties and original nutrition value such as frozen and pre-cut vegetables or fruit (Monteiro, 2009). Promoting consumption of MP-food instead of HP-food not only can it help preventing health consequences but it also reduces the environmental impact caused by the industrial processing (i.e., pollution due to the food industry, increased greenhouse gas emissions (Garnett, 2008). One possible strategy to achieve healthy and sustainable food choices is to strengthen the association between MP-food and the concepts of healthiness and sustainability through associative learning (Blechert, Testa, Georgii, Klimesch, & Wilhelm, 2016; Hoogeveen, Jolij, ter Horst, & Lorist, 2016).

1.1 Associative learning, food associations, and food choices

People's food choices can be influenced by physiological, psychological, cognitive, and economic determinants (Bellisle, 2003). However, associations and beliefs predominantly learned through experience regarding the health value, as well as the health consequences of consuming certain food also affect food choices (Hayes & Ross, 1987; Martin & Levey, 1978). Such associations can be changed through specific interventions (Capaldi, 1996). For example, associations between certain food categories (e.g., energy-dense food) and food-related information (e.g., health value) were successfully modified via *Evaluative Conditioning* (EC) (Hollands, Prestwich, & Marteau, 2011; Lebens et al., 2011; Verhulst, Hermans, Baeyens, Spruyt, & Eelen, 2006).

EC paradigm is used to strengthen or weaken the association between a target stimulus and an attribute concept by repeatedly pairing a neutral target (conditioned stimulus, CS) with a valanced concept (unconditioned stimulus, US). After applying EC, changes of the target-concept associations were observed at the implicit level, as assessed by the Implicit Association Task (IAT) (Greenwald, McGhee, & Schwartz, 1998), and at explicit level, as captured by explicit ratings of preference (Hofmann, De Houwer, Perugini, Baeyens, & Crombez, 2010). When healthy or unhealthy food images were paired with positively- or negatively-valenced faces respectively, participants who went through EC paring healthy food with positive faces showed stronger implicit associations between healthy food and positivity than those participants who went through EC paring unhealthy food with positive faces (Hensels & Baines, 2016). On the other hand, pairing fruits with positive stimuli (both words and images) increased three times the likelihood of selecting a fruit over a granola bar alternative in a snack-selection task (Walsh & Kiviniemi, 2014). Moreover, when snacks were associated with potentially-adverse health consequences through EC, participants showed more negative implicit associations towards energy-dense snacks, and significantly chose more fruits over snacks in a behavioral-choice task (Hollands et al., 2011). Furthermore, participants showed negative implicit associations towards snacks when fruit images were paired with slim female body-figures and overweight female body-figures with energy-dense snacks images (Lebens et al., 2011).

EC has been recognized as a unique type of learning which has effects not only on explicit evaluations but also on implicit and dynamic processing of evaluation formation with its distinctive qualities such as simplicity, independence of awareness, independence of contingency, and its resistance to extinction, sensitivity to counterconditioning, sensory preconditioning and US revaluation (Walther, Nagengast, & Trasselli, 2005). Indeed, EC works effectively in changing implicit and/or explicit associations between a target food (or food category) and related concepts such as *healthiness* (Hofmann et al., 2010; Hollands et al., 2011). However, the effect of EC on food choice has been investigated in experimental settings with limited external and ecological validity. Importantly, the evidence of EC effects is mainly based on behavioral tasks, with no reference to the neural underpinnings of such effects in the domain of food evaluation and food choice. Neural imaging techniques, especially electroencephalography (EEG) has been recognized as a useful tool in measuring the impact of evaluative conditioning on the change of attitude towards brand names that are not reflected in verbal responses measured by explicit and implicit behavioral paradigms (Bosshard, Koller, & Walla, 2019). Thus, the present study aims to fill these gaps by examining the neural processing underlying the effect of EC in changing food-related semantic associations.

1.2 Neural mechanism underlying associative learning, food associations and food choices

Several studies have investigated the neural mechanisms underlying food perception (Bielser, Crézé, Murray, & Toepel, 2016; Coricelli, Foroni, Osimo, & Rumiati, 2019; Mengotti, Foroni, & Rumiati, 2019; Toepel, Ohla, Hudry, le Coutre, & Murray, 2014), food categorization and semantics (Aiello, Vignando, et al., 2018; Foroni & Rumiati2017; Pergola, Foroni, Mengotti, Argiris, & Rumiati, 2017; Rumiati & Foroni, 2016; Rumiati, Foroni, Pergola, Rossi, & Silveri, 2016), as well as food valuation and decision making (Bielser et al., 2016; Camus et al., 2009; Francesco Foroni, Pergola, & Rumiati, 2016; Linder et al., 2010; Mengotti et al., 2019; Nijs, Franken, & Muris, 2008; Pergola et al., 2017; Plassmann, O'Doherty, & Rangel, 2007; Rumiati et al., 2016; Schacht, Łuczak, Pinkpank, Vilgis, & Sommer, 2016; Toepel et al., 2014; Vignando et al., 2018).

Some studies using Event-Related Potentials (ERPs) significantly singled out several components (e.g., N400) signaling conditioning in food contexts. Generally, the N400 waveform is a broad negative deflection of the ERP occurring 200–300ms after a stimulus with semantic information has been presented (auditorily or visually) and usually reaches the peak after 400ms (Lau, Phillips, & Poeppel, 2008). The semantic-priming paradigm as well as semantic congruency paradigm have been frequently used to tackle the N400 effect (Lau et al., 2008). Theoretically, N400 effect has been suggested to reflect the process of semantic integration of the critical word with the working context as well as the facilitated activation of features of the long-term memory representation associated with a lexical item (Lau et al., 2008). In the food contexts, semantic congruency was tested during continuous EEG recordings (Ma, Wang, Wu, & Wang, 2014). In this study words referring to salty and sweet foods were paired with disease-related risk information (e.g., "*causes diarrhea*" or "*causes obesity*"). Sweet-tasting foods paired with risk information elicited more conflict than salty foods, indexed by greater N400 amplitude. This result supports the idea that the N400 component is typically elicited by the presentation of semantically unrelated or conflicted information between words, images or contextual information (Kutas & Federmeier, 2011).

A smaller N400 amplitude has been observed at parietal sites when using a semantic-congruency task with food images as targets compared to non-food images when food images were primed with word denoting sensory food features (i.e., sweet and salty) ((Hoogeveen et al., , 2016). In the same vein, Pergola et al. (2017) used a semantic congruency task where participants were presented with sentences (prime) describing either a sensory feature of the food (e.g., '*It tastes sweet'*) or a functional feature (e.g., '*It is suitable for a wedding party'*), followed by an image of either *natural food* (e.g., cherry) or a *transformed food* (e.g., pizza). In this task, larger N400 amplitudes were observed when transformed food was paired with sensory primes, compared with natural foods, and *vice versa*, when paired with functional primes, indicating the semantic conflict between food types and sensory/functional properties of food stimuli.

Taken together these studies support the value of using ERPs markers such as N400 to investigate the associations between food categories and food-related information, with N400 being shown to track the integration of conflict between a food item and food-related information (Ma et al., 2014; Hoogeveen et al., 2016; Pergola et al., 2017). Moreover in the food context, the modulation of N1 and LPP components has been found, suggesting that both implicit and explicit processes are activated when images of neutral geometric shapes were conditioned using food tastes or non-edible tastes, with the former modulating the explicit ratings of pleasantness (Blechert et al.2016).

1.3 Eating habits and impulsivity

A conflict between the immediate, implicit impulsive responses (*impulsivity trait*) towards food stimuli and the deliberated, explicit decision-making processes (*restrained tendencies*) which include factors such as the health consequences of ingesting foods, has been shown in previous research (Carver, 2005; Hofmann, Friese, & Wiers, 2008). Indeed, an interaction between implicit and explicit associations based on food and food-related information has been suggested to be linked to deviant dieting behavior such as impulsivity towards food in obese individuals as well as to restrained eating behavior (Brunstrom, Downes, & Higgs, 2001; Carbine et al., 2017; Hoefling & Strack, 2008; Houben, Havermans, & Wiers, 2010; Roefs et al., 2011; Watson & Garvey, 2013). *Impulsivity* has been defined as the tendency of taking action without thinking, the difficulty in paying attention or concentrating, and the inability to plan beforehand (Fossati, Di Ceglie, Acquarini, & Barratt, 2001). In the domain of food-perception and behavior, the concept of impulsivity has become of great interest given its central role in eating disorders (Aiello, Ambron, et al., 2018; Aiello, Eleopra, Foroni, Rinaldo, & Rumiati, 2017). Obese individuals with higher impulsivity traits show more food-related impulsivity and less inhibitory control (Bartholdy, Dalton, O'Daly, Campbell, & Schmidt, 2016; Lavagnino, Arnone, Cao, Soares, & Selvaraj, 2016). *Restrained eaters*, on the other hand, tend to alternate chronic limitations of food intake in order to prevent weight gain or to promote weight loss with periods of overeating and thus have a higher risk of engaging in binge eating (Herman & Mack, 1975). It was shown that food–related information cues differentially influence eating behaviors in restrained and unrestrained eaters (i.e., *labeling*) while information cues (labels) related to healthiness or dieting modulate restrained eaters' consumption behaviors (Polivy & Herman, 2017). However, to our knowledge, no study has investigated how the effects of EC in changing food associations is modulated by individuals' differences such as impulsive characteristic and restrained tendencies.

1.4 The present study

Here we aimed at testing the effectiveness of an EC-based paradigm in (i) increasing the associations between MP-food and the concepts of *healthiness* and *sustainability*, (ii) increasing the selection of MP-food compared to HP-food, and the neural underpinning of these behavioral changes.

To test the neural underpinning of possible changes of food associations, a semantic congruency task together with EEG recording was implemented targeting the ERP neural marker N400. Moreover, the implicit and explicit associations between food and the concept of healthiness/sustainability were measured after the EC-based condition as well as after a control condition implementing the Implicit Association Test (Greenwald et al., 1998) and explicit ratings. Then, participants' food choice was recorded implementing a behavioral choice task: the *Virtual Supermarket task* (Waterlander, Jiang, Steenhuis, & Mhurchu, 2015).

We predicted that a successful EC-based intervention should: (a) increase the strength of associations between food-types (MP-food and HP-food) and the concepts (respectively, healthiness/sustainability and unhealthiness/unsustainability) at both the *implicit and explicit* levels (Fazio & Olson, 2003); (b) increase in the conflict between HP-food and concepts of healthiness/sustainability and/or the conflict between MP-food and concepts of unhealthiness/unsustainability as indexed by increased ERP waveform N400; (c) modify the behavioral choices of food-types. We also investigated whether the effect of EC varies across people depending on their level of restrained eating and/or impulsivity traits since both could be potential targets of clinical interventions. We predicted that people with higher impulsiveness may show greater changes of N400 amplitude after EC-based intervention as inhibitory control was shown to moderate the effect of EC on temptation and intake, with greater effects on people with low inhibitory control (Haynes, Kemps, & Moffitt, 2015). Finally, *Calorie Density* may also play a role in influencing participants' behavioral and neural responses to the newly acquired food-related information (e.g., *Degree of Processing* and *healthiness*), serving as a preexisting contextual information.

2. Material and Methods

2.1 Participants

Eighteen Italian healthy adults (10 males, *age range*=19-26, *mean age*±*SD*=22.22±2.41, *BMI range*=18-25, *mean BMI*±*SD*=21.61±2.53) with normal or corrected-to-normal vision participated in this study. However, one participant was excluded due to consistently positive-averaged amplitudes (> 2.5 SD of the group average) in the early N400 time window for congruent trials in control condition across all the electrodes included in the ERP analysis. This resulted in the final sample size of seventeen Italian healthy adults (7 males, *age range*=19-26, *mean* *age±SD*=22.41±2.35, *mean BMI±SD*=22.60±3.92). The Eating Disorder Inventory-3 (Garner, 2004) was used to exclude participants at risk of having eating disorder. Participants with dietary restrictions for medical, religious or personal reasons were excluded. The study was approved by the SISSA Ethics Committee and informed consent was obtained. Full disclosure was provided at the completion of the experiment through debriefing.

2.2 Procedure

Figure 1 depicts the experimental procedure and dependent variables. Participants went through two separate sessions in a counterbalanced order with approximate a week in-between (*mean*=8 days, *range* 7–12 days). In each session, participants went through *EC task* (EC-based condition or control condition), followed by the *Semantic Congruency (SC) task* during continuous EEG recordings. Participants then completed the IATs (Greenwald et al., 1998), the explicit ratings, and the Virtual Supermarket task. At the end of the control session, participants completed two questionnaires regarding restrained eating habits and impulsivity traits. The within-subject design allowed us to largely reduce the likelihood of biases or artifacts which may occur in between-subject design (De Houwer, Thomas, & Baeyens, 2001). At the same time, it provides more ecological validity in examining whether EC could be applied as an intervention to improve people's food choice and dietary patterns.

2.3 Stimuli

An independent sample of 21 Italian healthy normal-weight adults (5 males, *mean age±SD*=23.3±2.46, *age range*=20–28, *mean BMI±SD*=21.9±2.96) participated in a pilot study for stimuli selection. Participants rated 148 food images from FRIDa database (Foroni et al.2013), Food-pics (Blechert, Meule, Busch, & Ohla, 2014) and free sources on Internet on several characteristics using Visual-Analogue Scales (VAS). Eventually, 40 images of HP-food and 40 images of MP-food were selected as conditioned stimuli (CSs), with 20 images in each food group with a high-caloric density (kcal per 100g) and 20 images with low-caloric density (see Figure 2 for exemplar stimuli). The images were randomly assigned for EC-based condition and for control condition, resulting in the final set of 10 images per category (HPH: Heavily-Processed High-calorie; HPL: Heavily-Processed Low-calorie; MPH: Minimally-Processed High-calorie; MPH; MPL: Minimally-Processed Low-calorie). The results of independent *t-test*s showed that features of images were matched between conditions (Table S1, supplementary material). Detailed statistics per category of food images are presented in Table S2 (supplementary material).

Participants also rated in total 80 words and resulted in the final set of unconditioned stimuli (USs) containing 10 words for each of the concepts used both in the EC-based condition and in the control condition (Table S3, supplementary material).

2.4 Tasks

2.4.1 Evaluative conditioning (EC) task

The EC task adapted from Lebens et al. (2011) was used to strengthen the association between the concepts of healthiness/sustainability and MP-food as well as between the concept of unhealthiness/unsustainability and HP-food. A food image (CS) was presented in one of the four quadrants of the computer screen. Participants had to indicate the spatial location of the image. After the response via button press, the image disappeared and the word (US) representing the concept briefly appeared in the same position. In the EC-based condition, images of MP-food were always paired with words representing healthiness/sustainability, whereas images of HP-food were always paired with words representing unhealthiness/unsustainability. In the control condition, the CS–US pairings were randomized. The number of times that each paring appeared in one of the four quadrants was equal. There were 160 trials repeated twice per condition.

2.4.2 Semantic Congruency (SC) task during EEG recordings

The SC task assessing the congruency between food images and words related to [un]healthiness/[un]sustainability was run during EEG recording. Participants had to decide whether the concept of the word and the food image were congruent or incongruent (Figure 3). Inter-trial intervals were of random duration between 200-500ms. Responses were collected through button-pressing, and the response-key mapping was counterbalanced across participants.

To gain statistical power given the signal-to-noise ratio of EEG signals, we generated four images of each food item: (1) original image (e.g., dry figs); (2) flipped original image (left-right inverted: flipped dry figs); (3) another exemplar image representing the same food (a different image of dry figs); and (4) flipped second image (flipped second image of dried figs). This resulted in 640 trials (320 congruent trials and 320 incongruent trials) randomly divided into 8 blocks. Congruent trials were defined as trials in which images of MP-food appeared after the prime words representing the concept of healthiness/sustainability, or images of HP-food appeared after the prime words representing the concept of unhealthiness/unsustainability. Incongruent trials were defined as trials in which images of MP-food appeared after the words representing the concept of unhealthiness/unsustainability, or image of HP-food randomly appeared after the words representing the concept of healthiness/sustainability.

Continuous EEG was acquired at a sampling rate of 512 Hz with a 64-channel Biosemi ActiveTwo system (Biosemi, Amsterdam, Netherlands). Ag–AgCl electrodes mounted on an elastic cap filled with conducting gel according to the 10–20 system, referenced to the CMS-DRL ground. This reference served as a feedback loop, making the average potential across the montage closer to the amplifier zero (http://www.biosemi.com/pics/zero_ref1_big.gif). The topographic placement of electrodes can be found at www.biosemi.com. Data acquisition was made using the software Actiview 707-Laptop (www.biosemi.com).

2.4.3 Implicit Association Test (IAT)

To assess participants' implicit associations between MP-food/HP-food and attribute ([un]healthiness/[un]sustainability), adapted versions of the IAT (Greenwald, Nosek, & Manaji, 2003) were used (e.g., Coricelli et al., 2019), following the traditional IAT structure (Greenwald et al., 1998). Participants went through two IATs in a counterbalanced order: one with words representing healthiness/unhealthiness as attribute (IAT-Healthiness) and another with words representing sustainability/unsustainability as attribute (IAT-Sustainability). Each IATs consisted of two sessions, one for High-calorie food images and one for Low-calorie food images. In each IAT, first, participants had to sort food images relating to the food categories (MP-foods or HP-foods) with key "a" and key "l". Then participants had to sort word stimuli relating to the concept of healthiness/unhealthiness (or sustainability/ unsustainability). Third, participants sorted both food images and word stimuli into the combined categories (e.g., MP-foods/healthiness and HP-foods/unhealthiness) (arbitrarily considered compatible block). Then, the participants repeated the first step but with reversed response-key mapping. Finally, participants repeated the third step but with reversed response-key mapping (arbitrarily considered incompatible block).

2.4.4 Explicit ratings

Participants rated each food image through Visual Analogue Scale (VAS) ranging from 0 to 100. Three explicit ratings were used to assess participants' explicit evaluations towards food images related to: (i) Healthiness: "How healthy is the content of the picture for you?" ("very unhealthy"[0] "very healthy"[100]) (ii) *Sustainability*: "How sustainable is the content of the picture for you?" ("very unsustainable"[0] to "very sustainable"[100]); (iii) *Liking*: "How much do you like the content of the picture?” (“I do not like it at all”[0] to “I like it a lot”[100]). The order of the blocks as well as the order of presentation of stimuli within each block was randomized.

2.4.5 Behavioral choice task

The Virtual Supermarket (Waterlander et al., 2015) adapted to the Italian context was used to assess participants’ food choices. Participants were given an imaginary budget of €55 for one week of food consumption and were asked to choose among 521 products as many food items as possible that they would like to buy. An independent sample of 11 Italian healthy adults (5 female, *mean age*±*SD*=28.3±3.28, *age-range*=23-34, *mean BMI*±*SD*=22.7±2.39) rated all products for Degree of Processing from 0 to 10. Then we split food items into two categories of products according to the degree of processing (258 items of MP: *Degree of Processing mean*±*SD*=3.6±1.2; 254 items of HP: *Degree of Processing mean*±*SD*=6.1±0.7). The two categories of product significantly differed on the Degree of Processing ($t(410.89)=-30.53$, $p<.001$).

2.5 Questionnaires accessing eating habits and impulsivity

The Restraint Scale (Herman & Polivy, 1975) was used to assess participants’ eating behaviors. While the Barratt Impulsiveness Scale-11 (Patton, Stanford, & Barratt, 1995) assesses personal characteristic of impulsiveness and general impulsive behavior through 30 items responded using a 4-point scale. Higher total scores reflected higher levels of impulsivity. Scores for each subscale (i.e., Attentional, Motor, and Non-planning impulsivity) were also calculated separately.

2.6 Data analysis

2.6.1 Behavioral Data Analysis

Data from SC-task, IAT, explicit ratings, and behavioral-choice task were analyzed using SPSS 21.0.

For the SC task, we performed a 2(*Congruency*: incongruent vs congruent trials) x 2(*Condition*: EC-based vs control) x 2(*Degree of Processing*: HP-food vs MP-food) x 2(*Calorie Density*: High-calorie vs Low-calorie) ANOVA on accuracy and response time (RT).

For the IAT, the IAT-effect expressed by Cohen’s *d’* (Greenwald, Nosek, & Banaji, 2003) based in the response time of correctly responded trials, was analyzed with a 2(*Condition*: EC-based vs control) x 2(*Calorie Density*: High-calorie vs Low-calorie) ANOVA respectively for the concepts of healthiness and of sustainability. Larger IAT-effects indicate a stronger implicit association between MP-food and healthiness/sustainability and between HP-food and unhealthiness/unsustainability than vice versa.

For explicit ratings, three 2(*Condition*: EC-based vs control) x 2(D*egree of Processing*: HP-food vs MP-food) x 2(*Calorie Density*: High-calorie vs Low-calorie) ANOVAs were performed based on the mean ratings for each explicit rating (*healthiness*, *sustainability* and *liking*).

For the behavioral-choice task, a 2(*Condition*: EC-based vs control) x 2(*Degree of Processing*: HP-food vs MP-food) x 2(*Calorie Density*: High-calorie vs Low-calorie) ANOVA was performed on the numbers of purchased products, which indexed participants' behavioral choices.

2.6.2 Event-Related Potentials (ERPs) Waveform Analyses

EEG data-analyses were performed off-line using Cartool software (Brunet, Murray, & Michel, 2011).

2.6.2.1 <u>Preprocessing at single subject level</u>

During the offline processing, epochs were defined according to the experimental design, for congruent and incongruent trials (*Condition* × *Degree of Processing* × *Calorie Density*). EEG epochs were preprocessed and analyzed in the time interval from -98 to 684ms post-stimulus onset. The pre-stimulus period (-98ms to 0ms) served as baseline correction. EEG artifacts (i.e., eye blinks) were rejected (Semlitsch, Anderer, Schuster, & Presslich, 1986). Namely, inspecting the data trial-by-trial, trials which were exceeding ±80μV (artifact rejection criterion) at any electrode due to the artifacts such as eye blinks, muscle potential and other movements were excluded from the averaging. In average, 20% of datapoints were excluded per participant for EC-based condition while for control condition were 19% of datapoints. None of the participants presented and excessive amount of artifacts and therefore no subject was excluded during the preprocessing. The ERPs were computed for single electrodes before the ERPs were averaged across participants and plotted to visualize the waveform data. We analyzed waveform data from all electrodes as a function of time post-stimulus onset in a series of pairwise comparisons (*t*-tests).

2.6.2.2 <u>Group level analysis</u>

The N400 effect is characterized by a negative waveform between 300ms to 700ms post-stimulus onset. The early time window around 300-500ms and the later window around 500-700ms (Duncan et al., 2009; Pergola et al., 2017). Thus, our analyses focused on these time windows of interest. It is also possible that multiple negative components overlapping in time underlie incongruence detections, with different topographies, especially in tasks mixing verbal and pictorial stimuli (Hamm, Johnson, & Kirk, 2002; Pergola et al., 2017). With images stimuli, N400 effects were found at the more anterior brain regions (Kutas & Federmeier, 2011). Studies using food (Ma et al, 2014; Pergola et al., 2017) or non-food (Lau et al., 2008) images in semantic congruency task showed consistent results with N400 effect detected in left fronto-central regions. Other studies investigating neural mechanism underlying semantic associative learning paradigm also reported N400 in left fronto-central regions (Montoya, Larbig, Pulvermüller, Flor, & Birbaumer, 1996; Ortu, Allan, & Donaldson, 2013). Therefore, our analysis focused specifically on five electrodes in the left hemisphere, including frontal (F3, F5, F7) and central (C3, C5) regions according to the 10–20 system.

Segments were averaged separately for each food category and each condition, resulting in the mean voltage of each data point across trials (grand averages). Mean amplitudes of congruent and of incongruent trials in 2 aforementioned time-windows of N400 were extracted from the selected electrodes. Then two repeated measures 5-way ANOVAs were run separately for early and later time windows using a R package (Arcara & Petrova, 2014; erpR: ERP analysis, graphics and utility functions. R package version 0.2.0). Each ANOVA contained five factors: *Condition* (EC-based vs control), *Congruency* (incongruent vs congruent), *Electrode* (left F3, F5, F7, C3, C5), *Degree of Processing* (HP-food vs MP-food), and *Calorie Density* (High-calorie vs Low-calorie).

2.6.3 Correlation Analyses

First, we performed correlation analyses to investigate the relationship between the change of N400 and individuals' restrained eating behaviors as well as impulsivity traits. We calculated the difference of averaged amplitudes of ERPs for time windows of interest for HP-food and MP-food between EC-based vs control condition for incongruent trials as the index of changes of neural signatures. The more negative the number is, the greater change of the N400 effect is.

Second, in order to examine correlations between implicit behavioral changes and restrained eating behaviors/impulsivity traits, we calculated the difference of dependent variables between EC-based and control condition for incongruent trials, namely ACC and RT of SC task, as well as the IAT-effect.

3. Results

3.1 Behavioral Data

Table 1 shows *means* and *SD*s of (1) *accuracy* and *RTs* for each condition in the SC-task; (2) VAS-scores of explicit ratings; (3) number of purchased products in the behavioral-choice task. The *means* and *SD*s of IAT-effects are reported in Table 2. In the supplementary materials, Table S4 shows in detail the results of the 4-way ANOVAs on accuracy and on RT for SC-task. Table S5 shows results of the 3-way ANOVAs on VAS-scores of each explicit rating as well as on number of purchased products in the behavioral choice task.

3.1.1 SC task

Incongruent and congruent trials were analyzed. The results of the 4-way ANOVA on accuracy showed the significant interaction of *Condition* and *Degree of Processing*. The simple effects showed that accuracy for MP-food was higher in EC-based condition than control condition, $F(1,32)=7.82$, $p=.009$ (Figure 4). Moreover, accuracy for MP-food was higher than that for HP-food in EC-based condition, $F(1,32)=24.22$, $p=.000$. Regarding the significant interaction *Congruency*X*Degree of Processing*, accuracy of incongruent trials was higher for both HP-food and MP-Food than that of congruent trials, $F(1,32)=86.02$ and $F(1,32)=40.96$, $ps=.000$. In addition, for congruent trials, the accuracy of MP-food was higher than that of HP-food, $F(1,32)=33.75$, $p=.000$. For the significant interaction *Degree of Processing*X*Calorie Density*, accuracy for High-calorie items was higher than that for Low-calorie items within HP-food, $F(1,32)=61.66$, $p=.000$, while accuracy for Low-calorie items was higher than that for High-calorie items within MP-food, $F(1,32)=7.61$, $p=.000$. For the significant interaction *Condition*X*Congruency*X*Calorie Density*, the simple effects showed that for congruent trials in EC-based condition, accuracy for High-calorie items was higher than that for Low-calorie items, $F(1,32)=8.20$, $p=.006$; the same for incongruent trials in control condition, $F(1,32)=22.42$, $p=.000$. Moreover, accuracy for incongruent trials is constantly higher than that for congruent trials, $ps=.000$.

The results of the 4-way ANOVA showed that the main effect of *Condition* based on *RT*s was significant, $F(1,16)=4.51$, $p=.050$, with *RT*s in the EC-based condition being in general longer than in control condition.

3.1.2 IAT

For IAT-healthiness, only the main effect of *Condition* was significant, $F(1,16)=7.36$, $p=.015$. The IAT-effect was significantly larger after EC-based condition than control condition, showing the strengthened implicit associations between MP-food and healthiness and between HP-food and unhealthiness. There were no significant differences in the IAT-sustainability.

3.1.3 Explicit ratings

Three 3-way ANOVAs were performed on the ratings for each category of food images relative to *healthiness*, *sustainability*, and *liking*, respectively.

When looking at *healthiness*, the interaction *Condition*X*Degree of Processing* was significant. Specifically, healthiness ratings for MP-food was higher in EC-based than in control condition, $F(1,32)=11.94$, $p=.002$ (Figure 5). Ratings for MP-food was higher than for HP-food in both EC-based and in control conditions, $F(1,32)=167.66$, $p=.000$, and $F(1,32)=127.89$, $p=000$. The interaction *Condition*X*Calorie Density* was also significant. The healthiness ratings for Low-calorie food was higher in EC-based than in control condition, $F(1,32) =11.74$, $p=.002$. Ratings for Low-calorie food was higher than for High-calorie food in both EC-based condition and control condition, $F(1,32)=29.60$, $p=.000$, and $F(1,32)=4.86$, $p=.035$.

When looking at *liking*, the interaction *Condition*X*Degree of Processing* was significant. The rating on *liking* for HP-food was higher in EC-based than in control condition, $F(1,32)=9.45$, $p=.004$. Moreover, the rating for MP-food was higher than for HP-food in control condition, $F(1,32)=10.44$, $p=.003$. Second, the interaction *Condition*X*Calorie Density* was significant. The ratings on *liking* for High-calorie food was higher in EC-based than in control condition, $F(1,32)=23.79$, $p=.000$. The ratings for Low-calorie food was higher than the ones for High-calorie food in control condition, $F(1,32)=25.83$, $p=.000$.

No significant results were found for *sustainability* ratings.

3.1.4 Behavioral choice task

The interaction *Degree of Processing*X*Calorie Density* was significant. Specifically, participants chose more Low-calorie than High-calorie food within the range of MP-food (Figure 6), $F(1,32)=145.85$, $p=.000$. Moreover, participants chose more MP-food than HP-food within the range of Low-calorie food, $F(1,32)=108.95$, $p=.000$.

3.2 EEG Data

Table S6 (supplementary materials) shows results of the 5-way ANOVAs on the group-average data in the time window 300-500ms as well as 500-700ms post-stimulus onset for early and late N400 components, respectively.

3.2.1 Early N400 component (300-500ms)

The 5-way ANOVAs on the group-average data for early N400 component showed that the main effect for *Electrodes* was significant. The post-hoc Tukey's HSD test showed that averaged amplitudes of 3 electrodes in left frontal region (F3, F5, F7, in proximity of the dorsolateral prefrontal cortex [DLPFC]) and of 2 electrodes in left central region (C3, C5) differed significantly ($p<.01$), with frontal electrodes showing greater negative peaks.

The four-way interaction (*Condition*XCongruencyX*Electrodes*X*Degree of Processing*) was significant. The post-hoc Tukey's HSD test showed that averaged amplitude at electrode F7 for MP-food was significantly different between incongruent and congruent trials in EC-based condition (Figure 7a), $F(1,320)=4.05$, $p=.045$. Moreover, averaged amplitude at electrode C5 for MP-food showed significant difference between incongruent and congruent trials in EC-based condition (Figure 7b), $F(1, 320)=6.02$, $p=.013$. A pronounced negative deflection in the waveforms was found for incongruent trials. Topographic maps of the difference in amplitude between congruent and incongruent trials in the 300-500ms time window for MP-food in both EC-based and control conditions were shown (Figure 7c). We also found that in the EC-based condition, averaged amplitudes of congruent trials of HP-food and MP-food significantly differed at electrode C5, $F(1,320)=5.09$, $p=.025$. Greater negativity in the amplitude was found for HP-food.

The three-way interaction (*Congruency*X*Electrodes*X*Calorie Density*) was significant. The post-hoc Tukey's HSD test showed that the difference of averaged amplitude at electrode C5 for Low-calorie items was significantly more negative than High-calorie items for congruent trials, $F(1, 160)=10.95$, $p=.001$.

3.2.2 Late N400-like component (500-700ms)

The 5-way ANOVAs on the group-average data for late N400 component showed that the main effect for *Electrodes* was significant. The post-hoc Tukey's HSD test showed that averaged amplitudes of 3 electrodes in left frontal region (F3, F5, F7, in proximity of the dorsolateral prefrontal cortex, DLPFC) and of 2 electrodes in left central region (C3, C5) differed significantly ($p<.01$), with frontal electrodes showing greater negative peaks. Moreover, averaged amplitudes of electrode F7 differed significantly from the electrode F3 in the left frontal region) ($p<.01$), with greater negativity in the amplitude at electrode F7.

The three-way interaction (*Condition*X*Electrodes*X*Degree of Process*) was significant. The post-hoc Tukey's HSD test showed that averaged amplitude at electrode F5 for MP-food was significantly more negative in EC-based conditions than control condition, $F(1,160)=4.80$, $p=.030$. And the same for electrode F7, $F(1,160)=7.41$ $p=.007$. In addition, averaged amplitude of MP-food was significantly more negative than that of HP-food in EC-based condition at electrode F7, ($F(1,160)=4.46$, $p=.036$), and at electrode F5, $F(1,160)=3.94$, $p=.049$. Finally, electrode F7 showed greater negativity in the amplitude for HP-food than that of MP-food in control condition, $F(1,160)=5.59$, $p=.019$.

The three-way interaction (*Condition*X*Electrodes*X*Calorie Density*) was significant. The post-hoc Tukey's HSD test showed that averaged amplitude at electrode F3 was more negative for Low-calorie items than that for High-calorie items in EC-based condition $F(1,160)=10.66$, $p=.001$. However, averaged amplitude at electrode F7 was more negative for Low-calorie items than that for High-calorie items in control condition $F(1,160)=4.27$, $p=.040$.

3.3 ***Correlations***

3.3.1 Correlations between ERP waveforms and restrained eating/impulsivity traits

Changes in amplitude of the ERP early N400 waveforms between conditions for sematic incongruent trials for HP-food and for MP-food were correlated with individuals' restraint eating tendencies and impulsivity traits. The more negative the number is the greater change of the N400 effect is. There was a negative correlation between the sub-score of Barratt Impulsiveness Scale-11 (attentional impulsivity) and the changes of early N400 amplitude for HP-food at electrode F5 ($r=-.61$, $p=.010$) and F7 ($r=-.58$, $p=.015$) (Figure 8), suggesting that people with higher attentional impulsivity showed more change of early N400 amplitude for HP-food after EC intervention. Moreover, there was a negative correlation between the total score of Restraint Scale and the changes of early N400 amplitude for HP-food at electrode C3 ($r=-.49$, $p=.048$) implied that people with more restrained eating behavior showed more change of early N400 amplitude for HP-food after EC intervention.

3.3.2 Correlations between implicit behavioral changes and restrained eating behaviors/impulsivity traits

There was a negative correlation between the total score of Restraint Scale and changes of IAT effect for *Healthiness* within High-calorie item (*r*=-.51, *p*=.036), indicating that participants with more restrained eating behavior showed less strengthened implicit associations between MP-food and healthiness and between HP-food and unhealthiness within High-calorie items after EC.

For the dependent variables of SC-task, there was no significant correlation between the score of Barratt Impulsiveness Scale-11 as well as restraint eating scale and changes of ACC/RT.

4. Discussion

In the present study we investigated the neural mechanisms underlying semantic congruency of processed food evaluations by implementing an associative learning EC-based procedure.

4.1 EC as an effective paradigm to strengthen the associations between food and related information: behavioral effects

Longer RTs for both congruent and incongruent trials of the SC task in the EC-based session, compared to the Control session indicated increased semantic conflict between food-type and the paired concept. Importantly, the accuracy for MP-food was higher in EC-based condition than in the Control condition. These results suggest that EC can be effective in strengthened semantic associations between food and related information. Moreover, the accuracy for Low-calorie items was higher than that for High-calorie items within MP-food. Vice versa, accuracy for High-calorie items was higher than that for Low-calorie items within HP-food. The significant interaction between *Degree of Processing* and *Calorie Density* may be possibly due to the fact that the predominant associations between calorie density of food and the concept of healthiness (i.e., Low-calorie food is generally healthier) served as the contextual cue. This cue potentially influenced the newly acquired associations between the Degree of Processing of food and the concept of healthiness, with an automatic evaluative response to future inputs related to the same target (i.e., other MP-food items) that is in line with the value of the stored information (Fazio, 2007; Gawronski & Bodenhausen, 2006). Indeed, MP-food and Low-calorie food shared the same conceptual representation of healthiness. HP-food and High-calorie food shared the same conceptual representation of unhealthiness. While forming associations between food items and the concept of healthiness, participants seemed to integrate also the *contextual cues* (i.e., the information about calorie which predominately exist in their semantic memory) into the representation of evaluative information, resulting in the formation of *contextualized* *representation* for MP-food (see *Representational Theory*; Gawronski et al., 2015). Future studies are needed to determine the role of contextual cues, or newly acquired information, in changes of associations between targeted food and related information.

In line with previous studies that EC successfully modified the implicit and explicit associations between certain concept(s) and food, in our study the effect of EC on implicit associations paralleled the explicit results found on the healthiness ratings for MP-food, indicating a stronger association between MP-food and the concept of healthiness than the concept of unhealthiness after EC (Hermans, Baeyens, Lamote, Spruyt, & Eelen, 2005; Hollands et al., 2011; Lebens et al., 2011; Lescelles, Field, & Davey, 2003; Shaw et al., 2016; Verhulst et al., 2006). Further investigations could clarify whether the absence of changes of evaluation on the sustainability dimension is due to the fact that the environmental consequences of the food industry have only recently reached the general public (Garnett, 2008).

We failed to find a significant change in the behavioral choice between EC-based and control sessions. Overall, participants chose more MP-food and Low-calorie food across both sessions in the Virtual Supermarket. Moreover, participants chose more Low-calorie than High-calorie food within the range of MP-food while choosing more MP-food than HP-food within the range of Low-calorie food, despite our processed foods were equated on calorie density. This might suggest that participants' behavioral choice still largely depends on the predominant knowledge about calorie density rather than on the newly learned associations between the Degree of Processing and the concepts (e.g., healthiness), and that in real-life type of choice a EC intervention requires more time/repetition to translate into different choices. This result also calls into question the parallel between hypothetical choices used in other research (e.g., Camerer & Mobbs, 2017; Medic et al., 2016) and actual food choice in real-life choice that the supermarket task better simulate.

4.2 Neural signature of semantic congruency and associative learning

The main effect of *Electrodes* showed greater negative N400 amplitudes in the left frontal region (F3, F5, F7) compared to the left central region (C3, C5). Specifically, we found that the averaged amplitude of targeted N400 effects in the proximity of the dorsolateral prefrontal cortex (DLPFC, electrode F7) for MP-food was significantly more negative for the incongruent than congruent trials only in EC-based condition. Similarly, averaged amplitude of targeted N400 effects in the proximity of the temporo-parietal site (electrode C5) for MP-food was significantly more negative for incongruent than for congruent trials in EC-based condition. Our results suggest that the EC-based intervention effectively strengthened the semantic association between MP-food and the healthiness concept, supporting the notion that the early component of the N400 is a suitable index showing the change of associations between food and food-related information (Ma et al., 2014; Blechert et al., 2016; Hoogeveen et al., 2016; Pergola et al., 2017). Indeed, ERPs have been recognized as a useful measure to assess the impact of evaluative conditioning that is not reflected in responses which were measured by explicit ratings and the IAT (Bosshard et al., 2019).

Whether N400 components can be found in central-parietal or frontal topographies, and whether these sites share similar or different cognitive processes, is still debated (Bridger, Bader, Kriukova, Unger, & Mecklinger, 2012; Ma et al., 2014; Pergola et al., 2017; Voss & Federmeier, 2011). We found that changes of N400 effect were significant at the frontal electrode sites in proximity to the left DLPFC. There is overlap with the frontal electrode sites reported by Pergola et al. (2017) possibly due to the similarity between the tasks in relation to semantic congruency. However, our results contribute to better understand food evaluations, given the possible role of the left DLPFC in changing representations of information in working memory or forming new representations by integrating the stimulus feature with other types of information (Courtney, 2004; Kutas & Federmeier, 2000). However, there was also significant changes of N400 effect in the proximity of the left temporo-parietal site even though the average amplitude was less negative than that at the frontal electrode sites. This may imply the role of left superior temporal area in actively retrieving relevant semantic information from semantic memory (Kutas & Federmeier, 2000; Lau et al., 2008; Ruff, Blumstein, Myers, & Hutchison, 2008) as well as role of left inferior parietal area in feature integration and semantic categorization (Grossman et al., 2003). In sum, we confirmed the neural basis of changes of semantic incongruency effect elicited by the EC-based involving the fronto-temporal/parietal lexical-semantic network.

For the later time-window of 500-700ms, we didn’t find the changes of N400 effect between conditions. However, the averaged amplitude at electrode F5 and at electrode F7 for MP-food were generally more negative in EC-based conditions than in control condition. Moreover, the averaged amplitude at electrode F3 was more negative for Low-calorie items than that for High-calorie items in EC-based condition than in control condition. Thus, these late N400 waveforms may indicate the process of integrating newly acquired food-related information (e.g., MP-food and healthiness) into existing contextual information which is closely-related to the new information (e.g., Low-calorie density has been associated with the concept of healthiness). According to the *Representational Theory* (Gawronski et al., 2015), in our case, participants needed to decide whether food-types (e.g., MP-food/High-calorie food) were congruent with the concepts of unhealthiness in the SC-task after they just "learned" through associative learning the association between MP-food/High-calorie food and the concept of healthiness/sustainability via EC. However, the predominant association between Low-Calorie food and the concept of healthiness may have triggered a search for contextual factors that could explain the experienced discrepancy, integrating the newly acquired, counter-associated information into this contextual cue (i.e., calorie density) to form a new contextualized representation. Thus, the N400-like waveform we have found in the later time window might represent this process of integration of the newly acquired associations into a new contextualized representation (Packard et al., 2016), confirming the role of left DLPFC in maintaining contextual information to influence the selection of relevant representations over competitors (Badre, 2008).

Even though previous studies have shown that at the behavioral level, evaluative conditioning was more resistant to extinction than expectancy learning (e.g., Vansteenwegen, Francken, Vervliet, De Clercq, & Eelen, 2006), based on our results, future studies would have to examine (1) how long does the effect of EC-based intervention last on neural activity; (2) whether the effect of EC can be de-conditioned easily at neural level; and (3) whether extinguished evaluative learning can be reinstalled and be renewed (e.g., Luck & Lipp, 2020).

4.3 The role of left DLPFC in associative learning and impulsivity

The results of our correlation analyses suggest that individuals with higher attentional impulsivity showed more change of early N400 amplitude in the proximity of the left DLPFC for HP-food after EC intervention. People with more restrained eating behavior also showed more change of early N400 amplitude in the proximity of the left DLPFC for HP-food after EC intervention. This may due to the possible correlation between attentional impulsivity and restrained eating behavior found in our sample (r=.46, p=.062), supporting that high-restrained eaters may have a risk of overeating in case of coexisting impulsivity (Jansen et al., 2009). Our results implied that EC might be more effective in changing food associations for people with impulsive characteristics, for example, obese individuals, elder people, or people with dementia (Aiello, Vignando, et al., 2018; Mengotti et al., 2019; Vignando et al., 2018). This is particularly relevant as those groups of individuals are more likely to required interventions to improve their food choices. Similar to the present study, a behavioral study demonstrated that the implicit evaluation of unhealthy food became more negative after a training task associating unhealthy food with negative affect. Moreover, this effect led to lower snack consumption in individuals with low inhibitory control (Haynes et al., 2015). At neural level, the role of DLPFC in controlling goal-directed or stimuli-driven attention and action (cognitive control) towards food has been examined (Hare, Camerer, & Rangel, 2009; Hare, Malmaud, & Rangel, 2011) with the use of fMRI. Participants made healthier choices in the presence of health cues with DLPFC modulating the activity in ventromedial prefrontal cortex (encoding the value of the stimuli). Such results showed that exogenous attention cues can be an intervention to improve food choices and the neural mechanism underlying successful cognitive-control (Hare, Camerer, & Rangel, 2009; Hare, Malmaud, & Rangel, 2011). Further studies, possibly implementing other paradigms such as goal-directed reaching movements (e.g., Foroni, Rumiati, Coricelli, & Ambron2016), are needed in order to understand whether EC-based intervention can be an effective way for directly improving impulsive responses to food.

At behavioral, we didn't find significant correlations between impulsiveness/restrained eating behavior and the changes of ACC and/or RT of SC task. This may be explained by the fact that the neuro-physiological measurement (e.g., brain signals) is more sensitive in detecting change of cognitive activity as well as in differentiating cognitive process under the influence of food-related information (Kaneko et al., 2019). Moreover, the measurement at neural level such as event-related potentials are resistant to participants' response bias or strategy, compared to behavioral measurements (Kaneko et al., 2019).

5. Conclusion

The results from the present study demonstrated that EC-based intervention successfully strengthened the implicit and explicit associations between MP-food and the concept of healthiness at behavioral level. Consistently, after EC, pairs of unhealthiness/unsustainability concepts and MP-food food-types elicited greater N400 effects in the left frontal electrodes in the proximity of DLPFC, suggesting the role of DLPFC in changing or forming new representations by integrating stimuli's features with other types of information. Finally, significant correlations between the N400 effects in left DLPFC and individuals' level of impulsivity as well as restrained eating behavior implied that EC-based interventions might improve cognitive control towards food for individuals with higher levels of impulsiveness traits as well as higher restrained eating behavior. The present study provides a solid reference point to further examine the role of DLPFC and the effectiveness of EC in improving food evaluations and impulsive food choices.

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Conflicts of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Table 1. Results of behavioral tasks. Mean and standard deviation (SD) for each food-type in the SC task, explicit ratings (healthiness, sustainability and liking), and behavioral choice task (number of purchased products). Food stimuli abbreviations, HPH: Heavily-Processed High-calorie; HPL: Heavily-Processed Low-calorie; MPH: Minimally-Processed High-calorie; MPL: Minimally-Processed Low-calorie.

		EC-based condition				**Control condition**			
Task		**HPH**	**HPL**	**MPH**	**MPL**	**HPH**	**HPL**	**MPH**	**MPL**
SC- Incongruent trials Accuracy	*Mean*	0.74	0.90	0.81	0.84	0.82	0.69	0.76	0.78
	SD	0.15	0.14	0.12	0.13	0.09	0.12	0.10	0.12
SC- Incongruent trials RT (ms)	*Mean*	469.76	463.47	481.25	480.06	392.08	384.34	380.83	394.60
	SD	124.40	145.78	131.57	123.72	126.62	120.24	123.59	115.71
SC- Congruent trials Accuracy	*Mean*	0.31	0.24	0.54	0.54	0.35	0.31	0.42	0.48
	SD	0.22	0.18	0.16	0.17	0.20	0.19	0.13	0.14
SC- Congruent trials RT (ms)	*Mean*	482.53	485.65	463.69	471.77	390.56	409.46	409.97	398.00
	SD	134.09	119.92	138.50	128.65	120.65	117.22	115.26	115.75
Rating-Healthiness	*Mean*	29.65	36.22	65.32	74.32	28.48	32.91	61.98	63.85
	SD	10.83	9.76	10.85	10.68	9.91	8.17	8.36	10.79
Rating-Sustainability	*Mean*	35.04	37.40	69.31	73.99	32.38	36.33	70.16	68.93
	SD	14.49	13.39	10.67	11.81	16.71	16.48	10.46	10.59
Rating-Preference	*Mean*	57.54	54.53	62.86	61.95	44.12	55.42	59.31	66.62
	SD	13.88	13.48	10.62	15.51	16.21	16.22	12.34	8.53
Number of purchased products	*Mean*	3.18	3.88	4.88	24.00	2.94	4.53	4.53	24.71
	SD	3.76	3.06	3.76	9.62	2.22	3.28	3.69	8.57

Table 2. Results of the Implicit Association Test (IAT). Mean and standard deviation (SD) of the IAT scores (Cohen's *d'*) for High-calorie (HC) and Low-calorie (LC) food stimuli.

		EC-based condition		**Control condition**	
		HC	**LC**	**HC**	**LC**
IAT-Healthiness	*Mean*	0.82	0.75	0.62	0.47
	SD	0.34	0.47	0.38	0.41
IAT-Sustainability	*Mean*	0.59	0.66	0.63	0.53
	SD	0.37	0.50	0.44	0.44

Figure 1 Experimental procedure

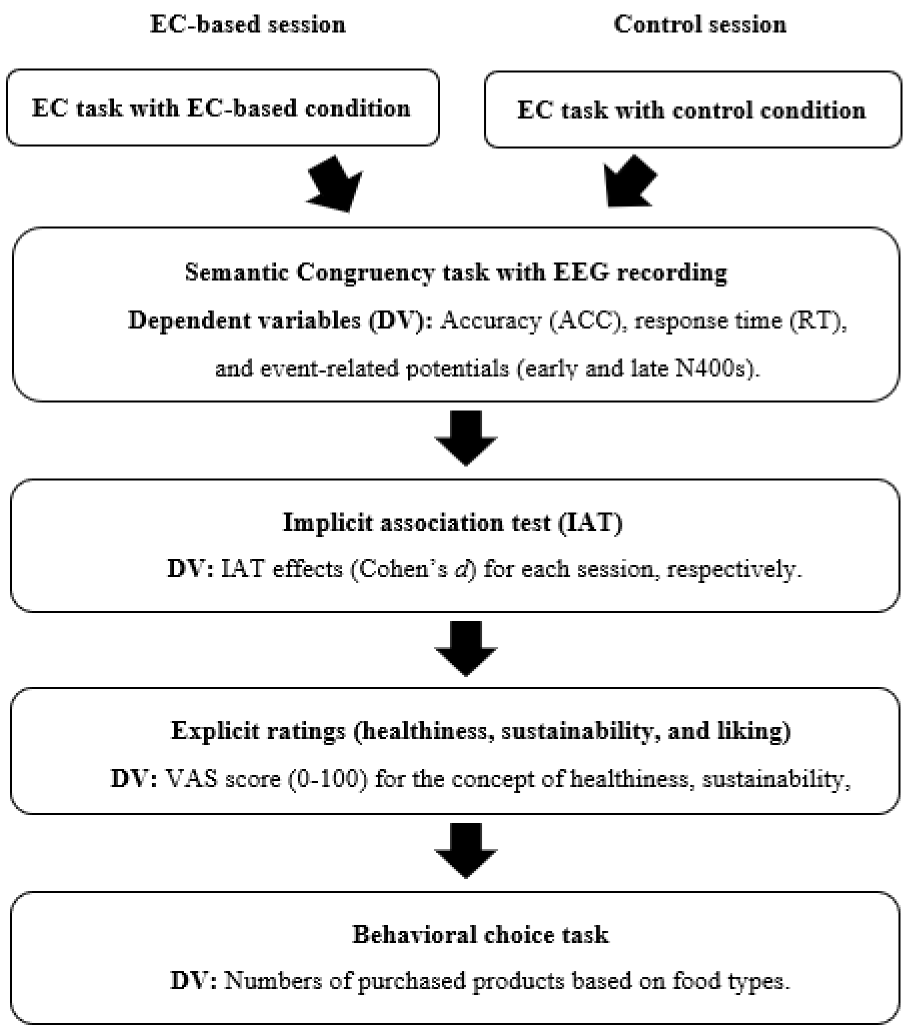


Figure 2 Exemplar images of *Minimally-processed* (MP) and *Heavily-processed* (HP) foods equated on average on *calorie density* (kcal per 100g). Original images were presented in color.

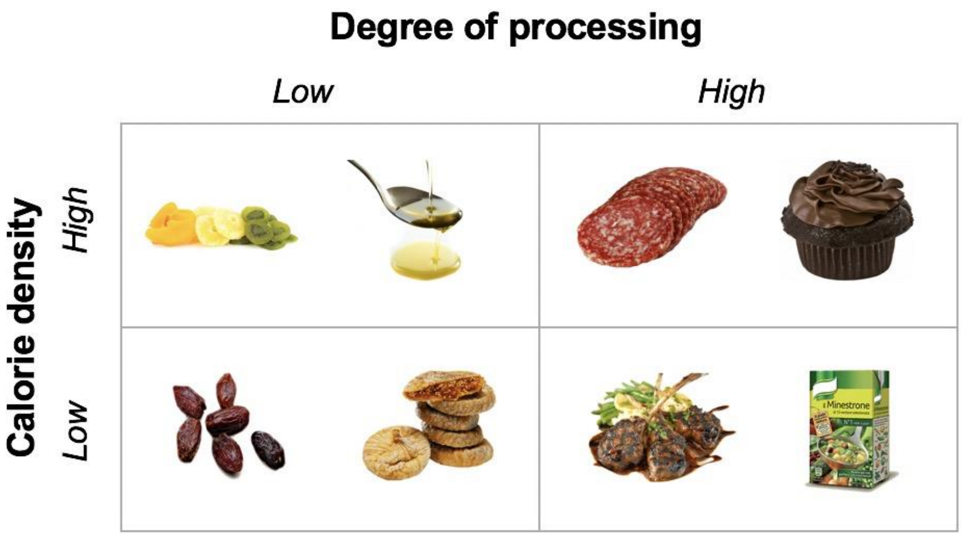


Figure 3 Exemplar trial structure of the *Semantic Congruency (SC)* task.

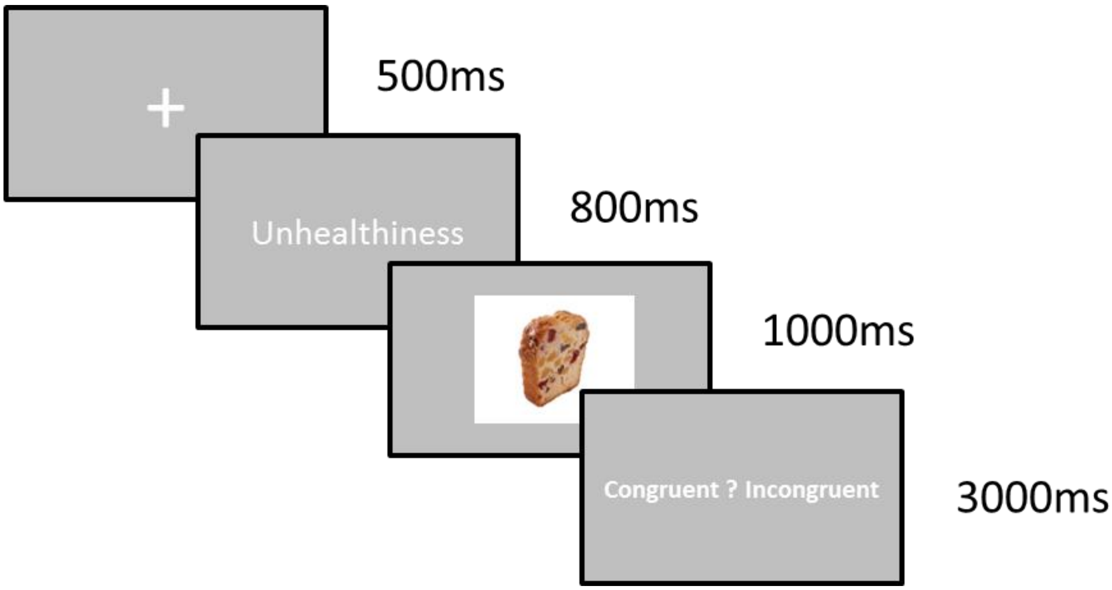


Figure 4 Semantic Congruency task (SC) accuracy results. Data of incongruent and congruent trials is reported for both control and EC-based sessions, for each *food-type*. The simple effect showing that the accuracy for MP-food was significantly higher in EC-based condition than in control condition, indicated with an '*'. Error bars indicate the standard error of the means.

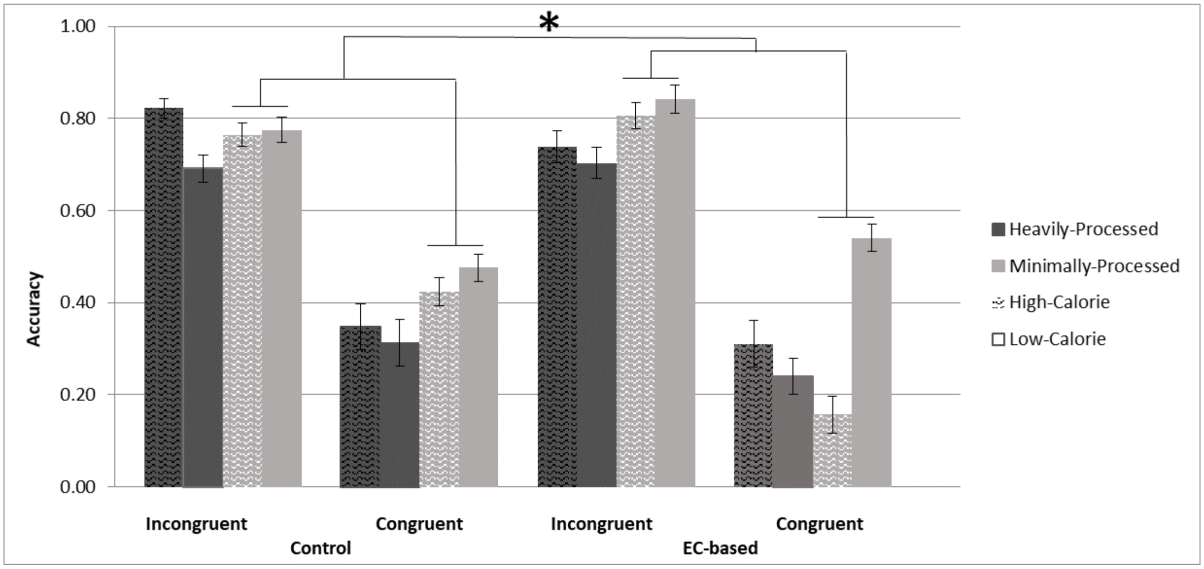


Figure 5 Explicit rating on Healthiness for each *food-type* for both control and EC-based sessions. The simple effect showing that the healthiness ratings for MP-food was significantly higher in EC-based than in control condition, indicated with an '*'. Error bars indicate the standard error of the means.

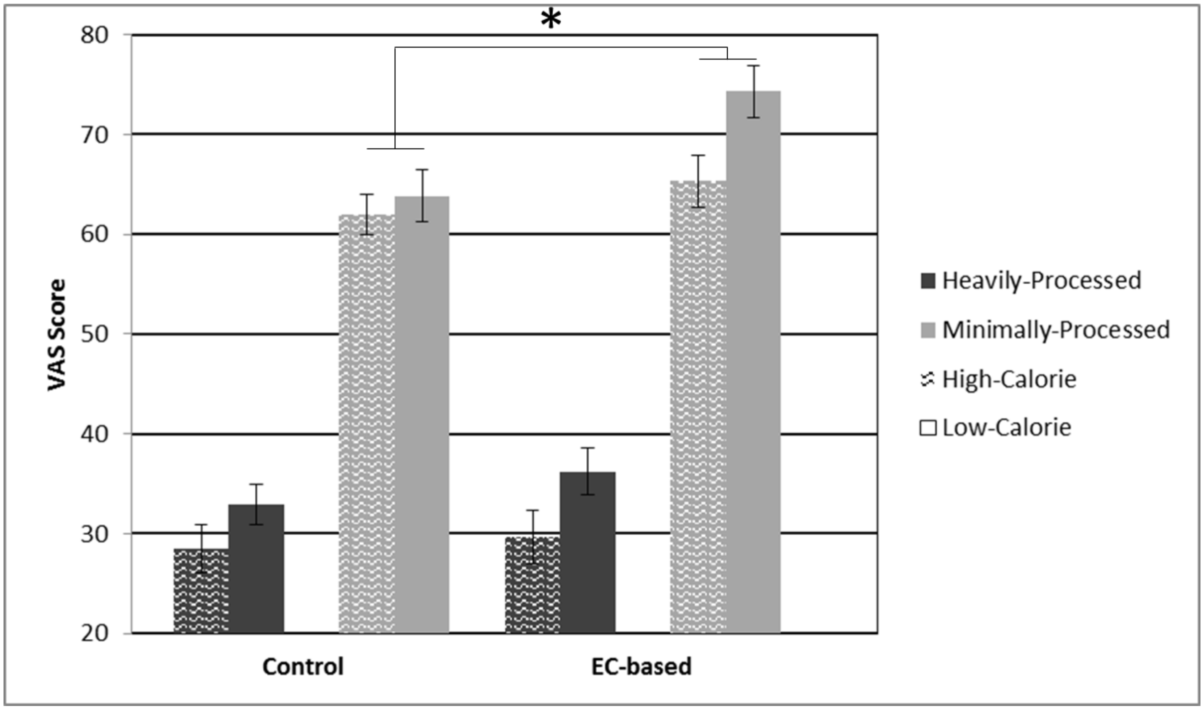


Figure 6 Virtual supermarket task results. Number of purchased products in both control and EC-based sessions, for each *food-type*. Simple effects showing that participants chose more Low-calorie than High-calorie food within the range of MP-food, as well as more High-calorie than Low-calorie food within the range of HP-food, indicated with an ‘*’. Error bars indicate the standard error of the means.

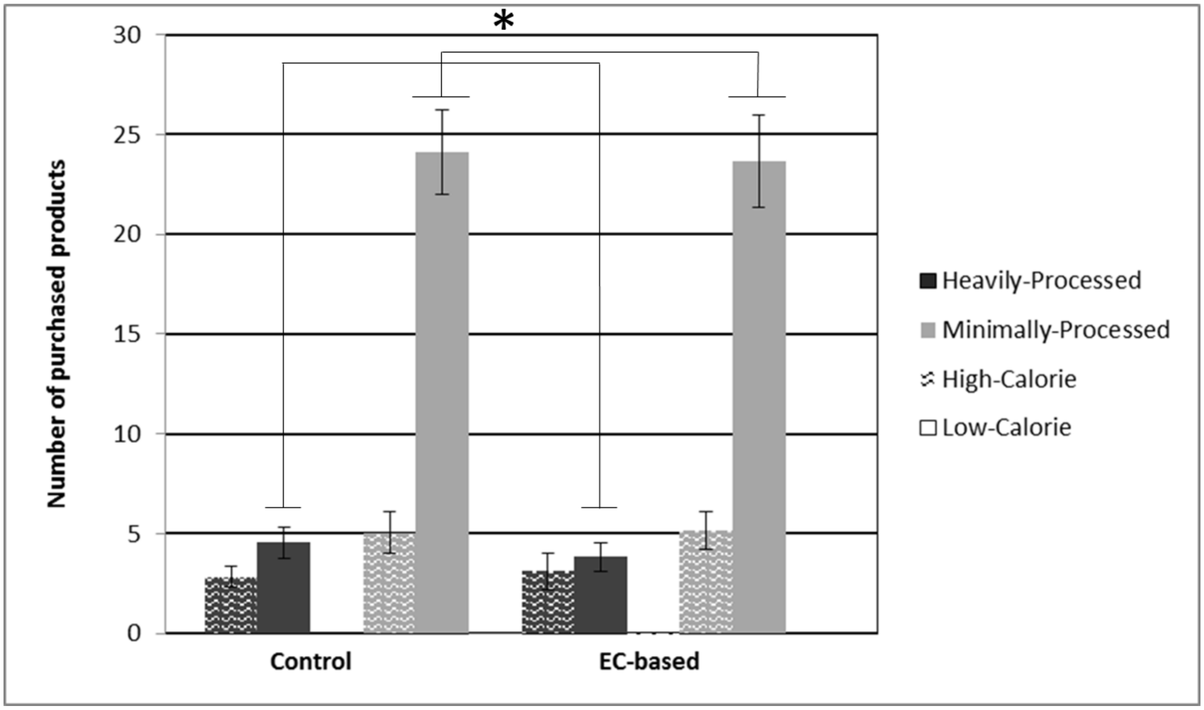
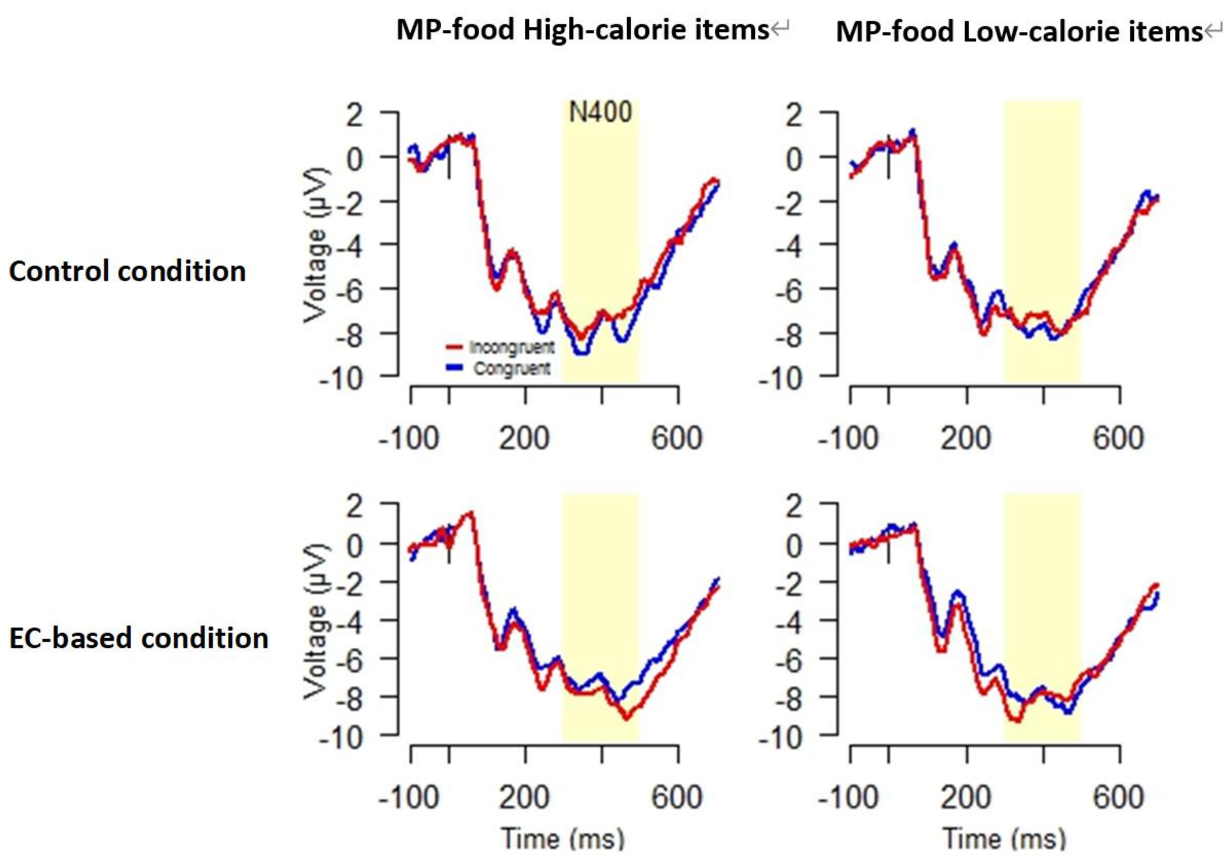
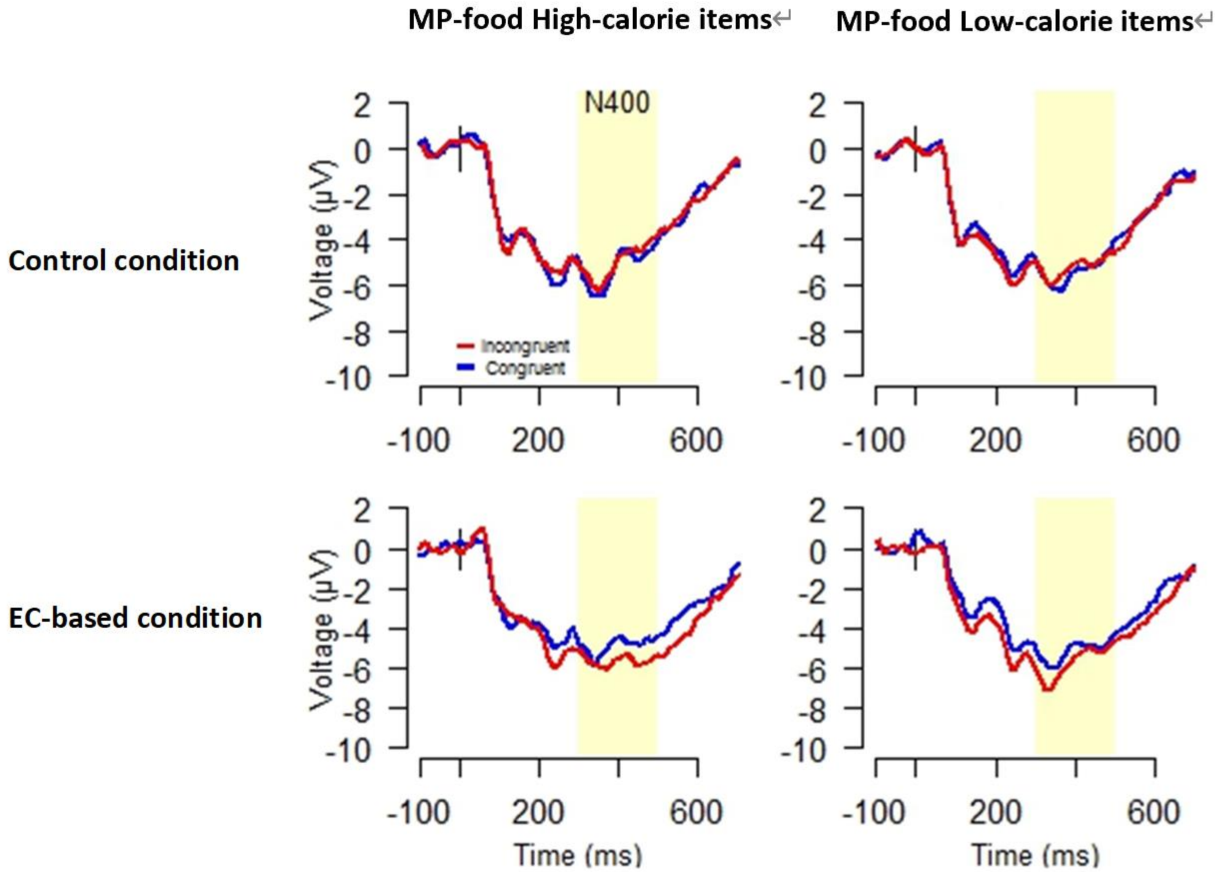


Figure 7 Results of EEG analysis showed a significant four-way interaction (*Condition*XCongruencyX*Electrodes*X*Degree of Processing*) for the early N400 effect. The post-hoc Tukey's HSD test showed that averaged amplitude at (a) electrode F7 as well as at (b) electrode C5 for MP-food was significantly different between incongruent and congruent trials in EC-based condition. A pronounced negative deflection in the waveforms was found for incongruent trials. (c) Topographic maps indicating the difference in amplitude between congruent and incongruent trials in *t*-value for MP-food in both EC-based and control conditions were shown for the 300-500ms time window.

(a)

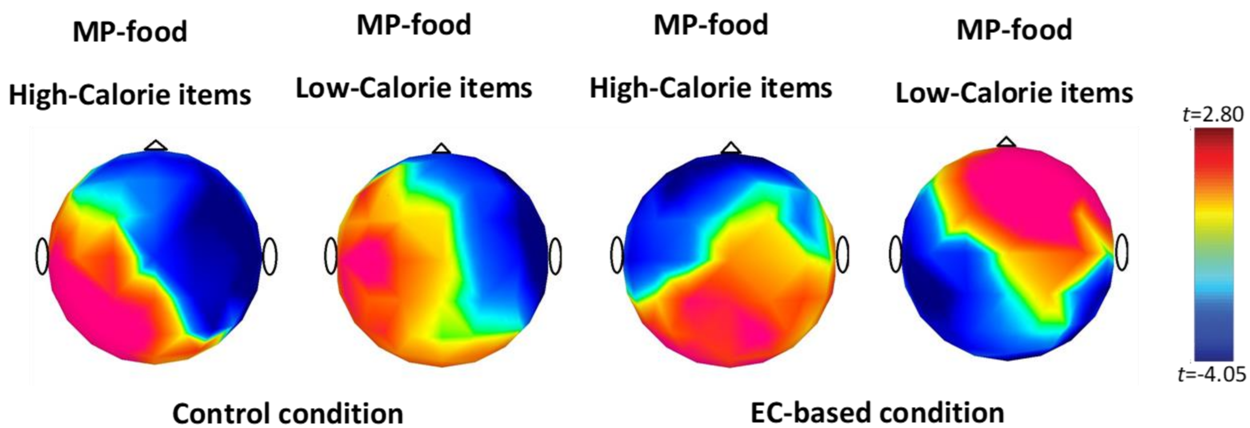


(b)



MP-food High-calorie items
MP-food Low-calorie items
Control condition
EC-based condition
N400
Voltage (µV)
Time (ms)
Incongruent
Congruent
2
0
-2
-4
-6
-8
-10
-100
200
600

(c)



MP-food
High-Calorie items
MP-food
Low-Calorie items
MP-food
High-Calorie items
MP-food
Low-Calorie items
t=2.80
t=-4.05
Control condition
EC-based condition

Figure 8 Negative correlations between (1) the sub-score of Barratt Impulsiveness Scale-11 (attentional impulsivity) and the changes of early N400 amplitude for HP-food at electrode F7 (upper); and (2) the total score of Restraint Scale and the changes of early N400 amplitude for HP-food at electrode C3 (lower). The more negative the number is the greater changes of the N400 amplitude is.