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Social cognitive and neural mechanisms of food choice under the influence of food-related information

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"Every story has an end, but in life every ending is just a new beginning."

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ABSTRACT

Food is the fuel of life. As such food stimuli are intensively processed by the human brain and the consequences of these processes, resulting in our food choice, have an essential impact on our life. Research suggested that food choice is largely guided by predominantly learned preference, and is likely to be influenced by information regarding the food (e.g., nutritional value) as well as by learned beliefs and associations (e.g., between a given food and its health value). This project aims at understanding at both behavioral and neural levels how these non-physiological factors might influence the food/drink choice and how they can be modified to improve our choice.

Chapter 1 includes the literature review on 1) how semantic information influences implicit/explicit associations toward food/drink, 2) the predictive validity implicit/explicit associations on food/drink choice, 3) the behavioral and neural evidence of changing associations, choices, and impulsivity control toward food/drink by implementing a conditioning paradigm (e.g. evaluative conditioning). The motivation and the objectives of my Ph.D. project are also presented here.

Chapter 2 contains Study 1 (Experiment 1 and 2). The *first* aim of the thesis is to understand how the association between a certain food and different concepts may guide our choices. This is addressed in Experiment 1 where I investigated how our choices can be predicted by preference and/or implicit associations between different constructs of interest (e.g., social status) and coffee and/or tea. People's self-report preference, implicit and explicit associations between different social constructs and tea/coffee were measured. Results based on 22 Italian healthy adults indicate that they possess strong implicit associations between tea and low social status, and this association significantly predicted choice of tea. The *second* aim of the thesis is to investigate whether the associations between food/drink and certain constructs can be changed through a classical learning paradigm, evaluative conditioning (EC), in which the associations between target drinks/food and food-related information was manipulated. This approach allowed us to investigate a possible strategy of intervention that could improve drink/food choices. This is addressed in Experiment 2 whereby a within-subject design is employed with participants going through both EC-condition and control condition. Results based on 68 healthy adults show that the implicit associations between tea and high-social-status, as well as the preference towards tea, significantly increase after EC. Most importantly, the difference in implicit associations across conditions significantly predict the

difference in choices of tea between conditions, indicating that changes in implicit associations determine changes in choice.

Chapter 3 is dedicated to the *third* aim which is to identify the neural mechanisms underlying the changes in association after EC between foods and the concepts of healthiness and sustainability. To this end changes in neural markers were related to changes in food choice as well as personal eating habits and individual difference in restraint eating and impulsive behavior. In Study 2, I experimentally strengthened the association between the concept of unhealthiness/unsustainability and heavily-processed food, and between healthiness/sustainability and minimally-processed food. A semantic congruency task combined with the Electroencephalography (EEG) technique was used to investigate changes in neural activity of the N400 in incongruent trials. Results on 18 healthy adults derived by comparing neural signatures of incongruent trials between conditions demonstrated that the magnitude of the N400 in left dorsal lateral prefrontal cortex (DLPFC) for minimally-processed high-calorie food significantly increased after EC. Thus, EC can be considered as an effective method to strengthen the semantic association between foods and a given concept, indexed by the change of neural signature tracking the semantic conflict. This increased magnitude also positively correlated with the Barratt Impulsiveness Scale score, indicating that the more impulsive a person is, the greater the change in magnitude of the N400.

Chapter 4 is devoted to address the *fourth* aim of the thesis that is to understand whether control of impulsivity over unhealthy food choice can be improved through the evaluative priming (EP) that is a variation of EC used in Study 2. Thus in Study 3, 15 healthy adults went through a pre-EP and a post-EP test including a Go/NoGo task combined with EEG. During EP, an increased subjective liking was found for Minimally-Processed Low-Calorie food images in evaluative block. For GNG tasks, at neural level, the averaged amplitude at left DLPFC for food images with evaluative priming was more negative in post-EP than in pre-EP GNG task. More negative N200 amplitudes were consistently found at left DLPFC in post-EP GNG task for Heavily-Processed Low-Calorie food as well as for Minimally-Processed Low-Calorie food. The behavioral and neural evidence showed the improvement of self-control towards food stimuli through evaluative priming. The possible role of left dorsal lateral prefrontal region in online value modulation and in integrating the stimulus feature with related information was identified, suggesting the self-control process based on deliberated thinking with symbolic representations and information operations.

In **Chapter 5** I summarized and discussed the main findings of my thesis. In short, my project provides the basic roadmap for understanding how food/drink related information affects cognitive and neural underpinnings of food/drink choices. Indeed, choices can be improved through modifying associations between food/drink and related information and thus healthy diets are encouraged. These results provide a potentially interesting research avenue well as possible interventions to modify and improve food/drink choices that could possibly be applied to individuals with eating disorders.

KEY WORDS: ASSOCIATIONS, EVALUATIVE CONDITIONING, FOOD CHOICE, EEG, DLPFC, IMPULSIVITY.

CHAPTER 1

General Introduction

Food stimuli are intensively processed by the human brain, and the resulting food choices have an essential impact on our life. In general, food choice is rooted in the nature of human behavior and guided by physiological needs (i.e., intake food to reduce hunger level or drinking water to reach homeostasis). However, through the development of human society, the way humans choose and eat food changed according to the evolution of natural environment, physical needs, life style changes, and development of technology. As a consequence of living in the industrialized society, overconsumption of high-calorie, over-sweet, and heavily-processed food has become the norm. This food consumption habit not only threatens our health condition but also has negative impacts on natural environment. Thus, the way to improve dietary behavior, essentially rooted in our daily-life food choice, remains a big challenge. Given that this is a problem that has become very critical in many countries, a multidisciplinary research to promote healthier food choices and better diets has received an understandably new impulse. The present PhD project seeks to obtain data to help filling this research gap and to provide insights into practical guidelines to develop successful interventions for improving food choices and eating habits.

1.1 Importance of food choices for well-being

We eat more than 1000 meals a year. One would expect that we should expertly know how much food to eat and which food is best for us (Wansink & Chandon, 2014). Instead, it has become increasingly clear that in developed societies, the ease with which we can access high-energy and palatable food contributes to promote excessive energy intake and unhealthy food choices, making us overfed but undernourished (Peters, Wyatt, Donahoo, & Hill, 2002). This means that we eat too much food relative to what would be biologically required, and we tend to eat potentially unhealthy food (e.g., highly processed, high-calorie, and high-fat food) that doesn’t provide all the necessary nutrients our body needs to stay healthy (e.g., vitamins and minerals).

Interestingly, food serves also other functions beyond sustaining life and satisfying sensory desire. For example, food also provides psychological benefits (e.g., making people feel healthy or providing means of social interactions, etc.) in different daily life situations. Therefore, people’s food choices and their diets are very important and influential for our physical and psychological well-being (Grunert et al., 2007). A recent work by Jacka and colleagues (2014) highlighted the importance of healthy dieting behavior and food choice for human well-being due to changes of global food systems (Jacka, Sacks, Berk, & Allender, 2014). Unhealthy dietary habits and food choices have become major risk factors for obesity, nutritional deficiencies, and several chronic diseases such as cardiovascular disease, cancer and diabetes (World Health Organization, 2014). For instance, the relation between the consumption of sugar-sweetened drinks and obesity has been supported by evidence that obese/overweight people had stronger implicit associations between sweet drinks and positivity (Ludwig, Peterson, & Gortmaker, 2001). Moreover, growing evidence suggests that unhealthy diets and food choices are risk factors also for mental disorders (i.e., eating disorders, depression, and dementia; (Jacka et al., 2014). Psychological distress has also been put in relation to unhealthy diets (Gibson, 2006; Polivy & Herman, 1999).

Given that the incidence of these diseases has considerably grown, promoting healthier food choices and better diets has been a new multidisciplinary research impulse. In order to reduce the large global burden of these physical and mental disorders, large scale initiatives (e.g., the collaborative project 'Food and Health Research in Europe' funded by the European Union) have been launched, substantiating the imperative for individuals and governments to improve population health by taking substantial actions in the domain of eating behaviors (Jacka et al., 2014). However, most of the research programs so far have focused on food and bio-technology, food safety, epidemiology, and nutritional surveillance. Within this multidisciplinary area only few studies have been conducted to investigate the social cognitive aspects of food choice and eating behavior. In particular, little attention has been payed as to how *socio-psychological constructs* represented by semantic information (e.g., social status, hedonic pleasure, healthiness, etc.) influence food choices. The understanding of such influence is important in order to guide the adoption of healthy and sustainable eating behaviors, and to identify an effective way to improve food choices. Existing interventions in food choice have shown some promises in increasing healthy food choice. However, they have some limitations in that they (i) rely on long and extensive training, (ii) work only in specific situations for specific target groups, (iii) are cognitively demanding, (iv) and rely on high-level of motivation. The current work will attempt to fill the gaps in our understanding of the factors that guide our food choice and how to possibly modify food choice.

1.2 The influence of socio-psychological constructs on food choice

The relevance of the socio-psychological context in food choice has long been recognized. For instance, in their study (Nestle et al., 1998) showed that understanding the influences of information derived from socio-psychological context is critical for the development of dietary recommendations, nutrition programs, and educational messages that will successfully promote dietary changes and help people adopting healthy diets. Factors such as cultural values, belief, and attitudes that have been shaped by social interaction or by media and advertising represent critical information about the societal level. At individual level, instead, food preferences, learning history, and knowledge about the food contribute mostly to our eating behavior (Nestle et al., 1998). Considering also the fact that we make on average more than 100 food-related choices every day (Wansink & Chandon, 2014) in a wide variety of daily-life situations (e.g., grocery stores, restaurants, vending machines, social events, home), and that specific food choices lay the groundwork for long-term food habits, understanding how to use the right food-related information to improve food choice is very important (Furst, Connors, Bisogni, Sobal, & Falk, 1996).

Of the food-related cues we are exposed in the modern society, semantic information is the most frequent type. Existing research has recognized the critical role played by semantic information such as the 'list of ingredients', 'nutrition panel', and 'health claims'. In their review, Cecchini and Warin (2016) concluded that the exposure to food labels as well as the use of food labels were crucial for strategies tackling unhealthy diets and obesity (Cecchini & Warin, 2016). According to Van Der Merwe et al. (2010), consumers who showed more interest in using labeled information were more inclined to use this information to make food choice. On the other hand, those who were not interested in using labeled information in their decisions depended more on previous experiences and habitual purchasing (Van Der Merwe, Kempen, Breedt, & De Beer, 2010). In addition, consumers with prior knowledge easily noticed and used food-related information in food decisions. Possessing nutrition knowledge indeed help people better understand the labels, and thus further improve food choice (Miller & Cassady, 2015).

Previous studies on the role of information in food choice have mostly focused on the effect of nutrition information disregarding the possible role that other types of information may have on food choice. For example, socio-psychological information (e.g., social status, hedonic pleasure, healthiness, etc.) has not been investigated, leaving their possible role in guiding food choice still to be understood. Moreover, the cognitive and neural mechanisms of food choice underlying the influence of food-related socio-psychological information is not clear. Furthermore, research consistently suggests that motivation of food-related semantic information use and prior knowledge on food do play an important role in influencing people's food choice and dieting behavior. It would be particular important to understand whether simple and effective strategies that do not rely so much on motivation and prior knowledge could be available and effective in improving/changing food choices. Based on these observations and arguments, I argue that it is important to identify the cognitive determinants of food choice and how they might be influenced by socio-psychological information in order to improve food choices.

1.3 Cognitive determinants of food choice: implicit and explicit associations

Nowadays, choosing what to eat can be a demanding task due to the excessive availability of food (Rozin, 1976). In fact, even if we have strong intentions and relatively good knowledge regarding which food is good for us, we still do not make the best choice most of the time. Bellisle (2003) proposed six main determinants of food choice: biological determinants (i.e., hunger, appetite, and taste), physical determinants (i.e., access, skills of cooking, and time), psychological determinants (i.e., mood and stress), and cognitive determinants (i.e., attitudes/preference, beliefs, and knowledge), social determinants (i.e., culture, family, and peers), and economic determinants (i.e., cost and income) (Bellisle, 2003). Of all the determinants, recent studies have focused more on the cognitive processes of perception, choice, and intake of food (Dalenberg et al., 2014; Evers, Adriaanse, de Ridder, & de Witt Huberts, 2013; Soussignan, Schaal, Boulanger, Garcia, & Jiang, 2015; Veldhuizen, Oosterhoff, & Kroeze, 2010).

Research on the cognitive mechanisms underlying food choice has recently provided an interesting view on these issues. One study has pointed out how food choice involves decisions based on external information inputs and conscious reflections (e.g., explicit association) as well as those that are automatic and based on habits (e.g., implicit association) (Furst et al., 1996). Indeed, our food choice or eating behaviors are not only the result of controlled processes but can be also influenced by predominantly automatic responses that are comparably fast, unintentional, and less effortful (Rangel, 2013). In line with this idea, previous research has proposed that food choice and eating habits are strongly affected by both implicit and explicit associations between food and certain concepts. On the one hand, explicit associations between an object and liking/disliking have been described as leading to the explicit evaluation towards objects in a decision-making process (Lichtenstein & Slovic, 2006); on the other, implicit associations between an object and a concept are supposed to represent a psychological tendency to evaluate an entity with favor or disfavor (Eagly & Chaiken, 1998).

In our daily life, people may possess particular implicit and explicit associations toward food (e.g., both coffee and tea can be associated to breakfast at home but coffee is a drink related more to social events than tea) which are thought to be predominantly learned (Martin & Levey, 1978; Rozin & Millman, 1987). Thus, a large body of literature has investigated how these associations are influenced by other information inputs, and how they can be modified. Despite the advancement in our understanding of such aspects, the relation between these associations and our choices is still not well understood (Czyzewska, Graham, & Ceballos, 2011).

1.3.1 Measurements of implicit/explicit associations towards food

Explicit associations represent people's deliberative evaluations (Gawronski & Bodenhausen, 2006; Petty, Briñol, & DeMarree, 2007). Usually, the measurements of explicit associations toward food are based on direct self-report, including ratings, questionnaires, or interviews. However, direct measurements can be biased by social desirability or self-presentation strategies (Egloff & Schmukle, 2003). In addition, they are unable to capture traces of past experience that are introspectively inaccessible to the individual (Verhulst, Hermans, Baeyens, Spruyt, & Eelen, 2006). Therefore, to address these limitations, indirect measurements were developed to capture and access implicit associations. Implicit associations often refer to triggered actions or judgments that are under automatically activated evaluations (Greenwald & Banaji, 1995). Thus, indirect measurements can be particularly useful in the domain of food choice considering that many possible sources of influence of our choice are not readily available to introspection (Roefs, Werrij, Smulders, & Jansen, 2006) and they have been implemented to access food-related associations (Czyzewska et al., 2011; Genschow et al., 2013; Sartor et al., 2011; Verhulst et al., 2006). Two indirect measurements have been frequently used for this aim, namely the Implicit Association Test (IAT) (A. G. Greenwald, McGhee, & Schwartz, 1998) and the priming paradigm (Fazio & Olson, 2003).

The IAT seeks to measure the automatic evaluations underlying implicit associations (A. G. Greenwald et al., 1998). The IAT has been implemented successfully in research investigating food associations with both normal-weight and over-weight participants. Previous studies using the IAT showed that compared to normal-weight adults, overweight/obese adults hold stronger implicit associations between sweets and positivity (Sartor et al., 2011). Healthy participants hold stronger associations between apple and positivity and between candy bars and negativity (Karpinski & Hilton, 2001). Similar results were obtained with the use of general categories (fruit/snacks) rather than single items (apple/candy) in the IAT (Perugini, 2005). In addition to food, the IAT was also used to successfully measuring healthy individuals' associations between juices and positivity and between sodas and negativity (Maison, Greenwald, & Bruin, 2001). Notably, modified versions of the IAT like the one introduced by Olson and Fazio (2004) with 'I like' /'I dislike' as attribute labels instead of 'positive'/'negative' suggest its potential to investigate implicit associations between food and attributes other than positive/negative (Olson & Fazio, 2004).

The second commonly-used indirect measurement is the priming paradigm, including both affective priming and semantic priming tasks. The priming paradigm, broadly speaking, allows for the measurement of affective or valenced associations to individual stimuli without being biased by the bipolar categories used in a categorization task such as IAT (Fazio & Olson, 2003). In fact, the IAT returns a measure that combines the associations between, for instance, apple and positivity and between candy and negativity. The IAT in its original structure does not allow to measure the association between a single category/item and positivity/negativity. On the other hand, the priming paradigm allows for such independent measurement. However, there are few examples of successful application of affective priming tasks in the examination of existing and newly acquired food associations (Lamote, Hermans, Baeyens, & Eelen, 2004; Verhulst et al., 2006). While both affective and semantic primings have been successfully implemented, a recent research suggested that compared to affective priming effect, semantic priming effect seems to be more robust across different types of task (i.e., categorization, lexical decision, and evaluation tasks), irrespectively of the type of stimuli presented (e.g., words or pictures). Moreover, affective priming only appeared when both prime and target came from a single semantic category. Thus, affective priming effect may be a more fragile phenomenon compared to semantic priming effect (Storbeck & Robinson, 2004).

In many research domains, IAT and priming paradigm have been extensively compared, showing the conditions under which they are better suited to capture the targeted implicit associations (Fazio & Olson, 2003). However, in the domain of food associations and choice, no research has investigated both paradigms within the same experiment, making this comparison particularly timely.

1.3.2 Predictive validity of implicit and explicit associations toward food choice

In the domain of food choice, one issue of interest pertains to the role played by implicit and/or explicit associations between food and concepts in food choices. The predictive validity of implicit and explicit associations toward food choice is still under debate, characterized by conflicting results. Research has suggested that automatic, implicit associations are often in contrast with deliberate, explicit associations (A. G. Greenwald & Banaji, 1995; Wilson, Lindsey, & Schooler, 2000) which might lead to differential predictive validity of choice according to different situations and the type of associations assessed. Based on the available evidence, Perugini (2005) described three general patterns of data on the relation between implicit and explicit processes in determining behavior. *First*, both explicit and implicit associations predict the behavior, explaining different portion of variance in an additive fashion (Richetin, Perugini, Prestwich, & O'Gorman, 2007; Spence & Townsend, 2007). *Second*, implicit and explicit associations interact in guiding behavior (Maison, Greenwald, & Bruin, 2004). In this instance, the interaction term between an implicit and explicit measure should be significant over and above the unique contributions of each measure. *Third*, the double dissociation pattern indicates that implicit associations predicted only automatic behaviors while explicit associations predicted solely deliberative behaviors (Friese, Hofmann, & Wänke, 2008; Perugini, 2005).

Many studies have pointed out the fact that in general, our decision-making process and choice are largely guided by implicit and explicit associations that are learned rather than innate (Martin & Levey, 1978). Nevertheless, to our knowledge, few studies have been done to examine the predictive validity of implicit and explicit associations especially between food and semantic information representing socio-psychological constructs towards food choice. Hence, it is important to understand how our daily-life food choices are determined by these cognitive processes, and whether food choice can be improved by changing the associations between certain food and certain semantic information.

1.4 Changing food choice: strengthening implicit and explicit associations towards food

Considering that unhealthy eating diet is responsible for a plethora of health problems, identifying an effective strategy to affect food choice and eating behavior is of paramount importance. Education, knowledge, or willpower have been reported to be *not cost-effective* and often discouragingly unsuccessful in changing eating behaviors (Wansink, 2015). One reason is that they resonate most strongly with people who are already vigilant and informed about health while the other individuals either do not pay attention because of being disinterested/resigned or do not have enough motivation to change food choice. Thus, alternative strategies need to be identified.

According to Rozin and Millman (1987), food choice among other behaviors is largely guided by learned implicit and explicit associations. Thus, associations between certain food/drink and related information could be targeted and modified to change food choices. This alternative approach focuses on influencing food-related associations (Ong, Frewer, & Chan, 2017) by implementing evaluative conditioning procedures (Johnsrude, Owen, Zhao, & White, 1999).

1.4.1 Evaluative Conditioning (EC)

Evaluative conditioning (EC) is based on the principle of associative learning. Through this procedure, a change in the valence of a stimulus should be observed after pairing that stimulus (conditioned stimulus, CS) with a positive or negative stimulus (unconditioned stimulus, CS) (Hofmann, De Houwer, Perugini, Baeyens, & Crombez, 2010). Not like Pavlovian conditioning which refers to a change in any type of response, EC focuses only on changing the evaluative responses to the CS. Due to this fact, EC has been used as a procedure for changing people's associations between stimuli and valenced attributes in studies investigating food preference, food choice, and eating behavior.

Few studies attempted to test whether EC can change implicit and explicit associations toward food, as well as to test the contribution of the changed associations to subsequent food choice. A meta-analysis conducted by Hofmann et al. (2010) suggests that EC effectively changes associations toward food but the reported changes are generally stronger for self-report than for implicit measures suggesting a possible limit of EC in changing implicit associations. However, Gawronski and Bodenhausen (2006) suggested that if the mutual interplay of the two associations (implicit and explicit) is considered, the pattern of results reported on the effect of EC procedures on implicit and explicit association can be reconciled. These authors formalized their contention in the Associative–Propositional Evaluation (APE) model which integrates possible patterns of associations change through EC. Specifically, they highlighted cases in which the two types of associations can change correspondingly or non-correspondingly. These authors claimed that change of implicit associations is guided by associative processes, characterized by mere activation which is independent from the subjective truth or falsity of the information associated. On the other hand, change of explicit associations is led by propositional reasoning that concerned the validation of evaluations and beliefs. Different patterns of associations change could be based on the particular way associative processes and propositional reasoning are affected by external influences. For example, EC successfully changes implicit but not explicit associations when the association between the CS (i.e., unhealthy snacks) and US (i.e., images of people displaying related diseases) is salient and participants are aware of the CS–US contingency (Gawronski & Bodenhausen, 2006).

This hypothesis was experimentally supported by a study by Hollands et al. (2011). In their study, compared to the control group, participants went through an EC procedure showed more negative implicit associations toward energy-dense snacks, especially for those who possessed more positive implicit associations toward snacks at baseline. Moreover, the same group of participants were more likely to choose fruit rather than snacks in a behavioral choice task and this choice was mediated by changes in individuals' implicit associations (Hollands, Prestwich, & Marteau, 2011). Similar results were obtained by Verhulst et al. (2006) who used an EC procedure to induce food (dis)likes by contingently pairing real food items with either sensory liking (actual tasting) or by providing expected consequences information. In fact, after EC, the results of picture–picture naming task demonstrated significant affective priming effects for both types of pairing (i.e., sensory liking and expected consequences information). This result also suggests that food associations were based on sensory liking or on (verbal) information about the expected consequences of eating the food. The study also investigated whether EC-induced changes predicted behavioral choice. However, only associations affected by 'sensory liking' predicted food-related choice behavior (Verhulst et al., 2006).

In brief, these studies implementing EC with food-related stimuli showed changes of implicit associations rather than explicit associations; in Gawronski and Bodenhausen's words, EC *non-correspondingly* changes of implicit and explicit associations (Gawronski & Bodenhausen, 2006). This might be due to the fact that these studies aimed at strengthening the associations between certain food and information on healthiness. Since people might possess already some predominant and salient explicit associations between certain food (i.e., low-calorie food) and healthiness information, it is possible that EC fails to change the explicit associations. Since implicit associations can be less affected by predominant and salient links, it is easier to modify the strength of implicit associations between certain food and information on healthiness by implementing EC. Further examination is needed to unravel the possible effect of EC in changing in associations between food (CSs) and food-related information (USs), implementing for instance other types of information in addition to positivity/negativity, healthiness, and sensory liking. Additionally, two important aspects in the literature are still need to be addressed. First, it is not well understood whether eventual changes in associations resulting from EC-procedure directly link and predict changes in food choice. Secondly, large attention has been increasingly dedicated to the neural underpinnings of food choice. Nevertheless, the neural correlates of food choice as well as the neural markers of changes in food associations are still largely unexplored. In the next section, literature on the neural mechanisms of food associations and food choice are reviewed.

1.5 Neural mechanism underlying food associations, food choice, and changing food choice

The focus of recent research investigating food choice also draws attention to the underlying neural mechanism implementing both functional Magnetic Resonance Imaging (fMRI) and EEG. The MRI provides good spatial resolution while EEG has been implemented mostly to investigate temporal dynamics of stimuli processing (Huettel, Song, & McCarthy, 2004; Zurawicki, 2010). The benefit of integrating these imaging techniques with more traditional approaches (e.g., explicit ratings, questionnaires etc.) has been highlighted in a recent review in relation to the investigations of the processes involved in food decision making (e.g., the influence of associations and emotions on choices) (Stasi et al., 2018). As it will become apparent in the next few sections, a growing literature now addresses this integrative effort. In section *1.5.1*, studies on food in general will be briefly introduced, followed by the literature focusing on neural mechanism of food associations (e.g., food perception, emotional and cognitive valuation of food, us of food labels, and the influence of semantic information regarding the food) and how theses associations may affect food choice. In section *1.5.2*, studies investigating neural correlates of changes in food associations and food choice through interventions (i.e., EC) will be introduced.

1.5.1 Neural correlates of food associations and food choice

Research on the neural mechanisms associated with primary sensory responses to food-related stimuli is rich (Sørensen, Møller, Flint, Martens, & Raben, 2003; L. N. van der Laan, De Ridder, Viergever, & Smeets, 2011). A meta-analysis of recent research implementing fMRI technique with healthy population highlighted the primary role of the visual system in food selection (van der Laan, De Ridder, Viergever, & Smeets, 2011). In particular, compared to visually processed non-food, visually processed food cues involved the bilateral activity of the posterior fusiform gyrus, the left lateral orbitofrontal cortex

(OFC) and the left middle insula. Moreover, the responses to food pictures in the right amygdala and left lateral OFC are modulated by participants' hunger state, while energy level (e.g., calorie content) modulates the response in the hypothalamus and ventral striatum (L. N. van der Laan et al., 2011). However, the most consistent finding in their meta-analysis was reported in about 40% of the studies. Thus, we should acknowledge the complex nature of food stimuli and the inconsistency of the findings of the existing literature on neural correlates of the processing visual food stimuli. More studies using visual food stimuli are needed in order to clarify these aspects and to provide a more systematic account for its neural underpinning.

A second line of research focuses on the neural mechanisms of (i) associations between food and information (e.g., low-calorie food is associated with the concept of healthiness), (ii) how the association can be influenced by food-related information, and (iii) how associations may contribute to food decision-making. In this domain, EEG and in particular event-related potentials (ERPs) have been implemented to investigate how brain activities are modulated by associations and valuations (e.g., emotional valence or cognitive component like preference) and how neural markers are correlated with food choices. Indeed, ERPs can serve as the precise and objective indicator of the process of food associations and valuations (Schacht, Łuczak, Pinkpank, Vilgis, & Sommer, 2016). Early ERP components are related to the sensory process or emotional responses indicating food perception or affective valuation (e.g., positive or negative), while later ERP components are related to semantic processing indicating cognitive valuation (e.g., healthiness).

Several studies have distinguished these two different phases of processes and their relation to food choice (Bielser, Crézé, Murray, & Toepel, 2016; Grabenhorst, Schulte, Maderwald, & Brand, 2013; Nijs, Franken, & Muris, 2008; Toepel, Ohla, Hudry, le Coutre, & Murray, 2014). Moreover, food-related information has been found to play an influential role in these processes. For instance, evidence of an early stage of food perception processing has been provided by Bielser et al. (2016). These authors asked participants to rate how much they liked a series of food items (valuation) and then to choose between two alternative food options displayed. Behaviorally, foods that were liked more strongly were also rated faster and chosen faster and more frequently. Interestingly, the authors also demonstrated that spatio-temporal brain dynamics of food viewing (visual evoked potential (VEP) around 135–180ms after food image onset) were modulated by the interaction between food liking and the subsequent choice. Source analyses showed that these neural activities were possibly generated in the insula, dorsal frontal and superior parietal regions, which are thought to be involved in salience and reward attribution as well as in decision-making processes (Bielser et al., 2016). Indeed, the ventral striatum has been suggested to be part of the reward system during the presentation of food (Beaver et al., 2006; O'Doherty, Buchanan, Seymour, & Dolan, 2006; Stoeckel et al., 2008) as well as in cognitive valuation of food (i.e., preferences; (Laura N Van der Laan, De Ridder, Viergever, & Smeets, 2012)), buying behavior, and processing information regarding health. On the other hand, right dorsal lateral prefrontal cortex (DLPFC) seemed to be a part of a general valuation system for food (Camus et al., 2009; Linder et al., 2010; Plassmann, O'Doherty, & Rangel, 2007). Interestingly, food-related information (i.e., food labels) has also been found to increase neural responses in the reward system in making food choices. In an fMRI experiment Linder et al. (2010) presented participants with food with conventional label or with a widely-known symbol for organic food. Increased activity in the ventral striatum as well as the DLPFC was found for foods with "organic label" compared to those with conventional labels. Moreover, there was a positive correlation between ventral striatal activity in response to food labelled as organic and the frequency of purchasing organic food (Linder et al., 2010).

Evidence of an early emotional valuation of food and its relationship with subsequent food choice has been also reported. Key regions involved in emotional processing like the amygdala have been also reported to be involved in food decision making (Grabenhorst et al., 2013). Moreover, in food choice tasks, decision is influenced by information provided (e.g., labels). For example, healthy, mildly hungry adults performed a food evaluation task and a food choice task after pairs of identical food picture were paired with simple labels that emphasized either taste benefits or health-related food properties. The labels biased the food evaluations on health-related food properties, indexed by increased activation in the amygdala, which predicted behavioral shifts towards healthier choices. The result suggested the active participation of emotional system of food evaluation that contributed to the food choice (Grabenhorst et al., 2013).

Evidence of a later cognitive valuation toward food has also been described. Nijs et al. (2008) showed a larger positive potential (P3, around 300ms after stimulus onset) and a late positive potential (LPP, around 600ms after stimulus onset) were elicited by high-calorie food pictures, compared to pictures of neutral objects (i.e., office items). These results were interpreted as indicative of a two-step processing of food items with a rapid affective response and a later evaluative stage (Nijs et al., 2008; Schacht et al., 2016). Toepel et al. (2014) further examined how external food-related information impacts sensory processing and cognitive valuation (e.g., preferences) of food in order to build an integrative understanding of food consumption behavior and to provide potential means of preventing long-term health problems by interfering with deviant eating patterns. In their study, significant interaction of VEPs in response to food pictures (high- and low-calorie foods) preceded by labels (with positive, negative, or neutral valence) was found over the 260–300ms post-stimulus period, especially when high-calorie foods were preceded by labels with positive valence compared to neutral labels. Neural sources were generated in occipital, posterior, frontal, insular and cingulate regions. These results indicated the influence of affective food-related information on cognitive valuation of food (Toepel et al., 2014).

More recently, a new line of research implementing EEG provided good examples of how the technique is suitable to be implemented also in food decision research when more elaborate stimulus material is used instead of single valenced word (e.g., socio-psychological information related to food, given the information on possible diseases, and sensory and functional attributes, etc.) to create more realistic situation (Ma, Wang, Wu, & Wang, 2014). In addition, this research line focuses on characterizing neural correlates of food associations and food choice under the influence of food-related information inputs. Ma and colleagues (2014), for instance, investigated how neural correlates of food evaluation are influenced by the health claims (e.g., information on possible diseases that arise with food consumption). The results are providing interesting insights into the processing and integration of different food and different types of risk-related information. When presented with the disease-related risk information, sweet-tasting food elicited more conflict than salty food, indicated by a negative ERP component between 250–500ms (i.e., N400). Moreover, information containing chronic diseases aroused a stronger emotional (fear) response than acute diseases, indicated by the late positive potential (LPP) at 500–800ms (Ma et al., 2014). These results first support the notion that N400 can be used as a marker that signals conflicting information (e.g., food item and health value) (Ma et al., 2014). Secondly, LPP components seem to be able to differentiate different levels of emotional arousal not only in general (Flykt & Caldara, 2006), but most importantly, also in the context of food-related risk information (Ma et al., 2014). In sum, different neural markers may reflect different neurocognitive processes of food evaluation and the possible contribution of food-related information.

Using EEG, Hoogeveen and colleagues (2016) investigated the neural correlates of the association between certain concept (prime) and targeted food (i.e., priming effect) (Hoogeveen, Jolij, ter Horst, &

Lorist, 2016). The authors assessed the differential strength of food associations implicitly stored in memory. Participants performed a picture-categorization task, in which food or non-food target images were primed with three different types of words: sensory prime like taste (i.e., sweet and salty), non-sensory primes like healthiness (i.e., healthy, unhealthy), or eating context (i.e., breakfast, dinner). The prime-target pairs were either congruent or incongruent in meaning. The authors reported a smaller N400 amplitude at the parietal regions when categorizing food as compared to non-food images, indicating more congruent associations between food-related primes and food images targets, compared to non-food images targets. This effect was more prominent for trials containing food-related word primes and food images, particularly if the prime was sensory in nature (Hoogeveen et al., 2016). The relevance of sensory association is also supported by the results of a EEG study implementing a semantic congruency task associated with the N400 (Pergola, Foroni, Mengotti, Argiris, & Rumiati, 2017). A sentence (prime) was presented to participants, followed by a picture of either natural food (e.g., cherry) or a transformed food (e.g., pizza). Primes described either a sensory feature ('It tastes sweet') or a functional feature ('It is suitable for a wedding party') of the food. Participants had to decide whether prime-food pairs were congruent or incongruent and N400-like components were investigated. Semantic processing induced significantly different N400 according to the type of food and the type of prime, with larger amplitude for transformed food than for natural food when paired with sensory primes, and *vice versa* when paired with functional primes (Pergola et al., 2017).

Taken together these studies suggest, first, that sensory associations are important features of food memory and primary motives in food choice. Secondly, the research reviewed provides evidence that this approach can be suitable to investigate the neural correlates of food processing and the role played by associations between food and socio-psychological information in food perception and food choice. In particular, the semantic paradigm (e.g., sematic priming or congruency tasks) combined with EEG seems to be particularly suitable to investigate associations between food and related-information.

1.5.2 Changing food choice and its neural correlates

From the research reviewed thus far, the behavioral evidence does support the idea that EC can be an effective procedure to change food associations and to further influence food choice. Nevertheless, very few studies have explored the neural mechanisms underlying such an EC effect. Blechert et al. (2016), for instance, claimed that the conditioning paradigm can be a fundamental solution to the problems of hedonic overeating. In their study the authors investigated the behavioral and ERPs correlates of naturalistic appetitive conditioning. Geometric objects associated with edibility and marzipan taste (CS+) were paired with sweet taste (US) while geometric objects were associated with non-edibility and plastic taste (CS-) in a single trial. Picture-viewing blocks of the geometric objects with pleasantness ratings were collected prior to conditioning (pre-conditioning) and after conditioning (post-conditioning). Moreover, participants' state-craving for sweet food was assessed by the Food Craving Questionnaire both at pre- and post-conditioning. From pre- to post-conditioning, an early negative ERP component around 100ms (N1) decreased and a LPP enhanced only for the CS+. In addition, participants with increased state-craving from pre- to post-conditioning showed stronger N1 and LPP modulations. Also, ratings on pleasantness selectively increased for the CS+ but not for the CS−. Based on the results, the authors suggested that two stages are involved in a craving-related process of food: an early implicit (attentional) stage and a later explicit stage (motivation related to the meaning of the stimulus) (Blechert, Testa, Georgii, Klimesch, & Wilhelm, 2016).

However, this interpretation could be questionable as similar results were found also in a study unrelated to food stimuli the neural processing of associative learning on previously-meaningless pseudowords was investigated (Kuchinke, Fritsch, & Muller, 2015). In such study Kuchinke and colleagues used an evaluative conditioning task in which pseudowords (CSs) were associated with either positive, neutral or negative pictures (USs). Participants then were presented previously-conditioned pseudowords together with new pseudowords in a recognition memory task while their ERPs were recorded. A post-experiment rating task for emotional valence on each conditioned stimulus was also included. Both recognition accuracy and valence ratings confirmed that EC successful strengthening the association between pseudowords and valence. Two early modulations of the ERPs around 100ms (P1 and N1) at medial-frontal brain regions discriminated pseudowords conditioned with positive vs negative valence pictures. Moreover, conditioned and new pseudowords were also differentiated but at later processing stages, as indicated by the modulation of the LPP (Kuchinke et al., 2015). Thus, early ERP components (e.g., P1 and N1) seemed to reflect implicit, automatic processing of stimuli (e.g., emotional and/or attentional process) while later ERP components implied the explicit, reflective cognitive process (e.g., stimuli discrimination and evaluation). These results parallel the one found in the food domain questioning the specificity of the EC effect on food associations.

Considering the scarcity of research testing the neural mechanism underlying the effect of EC on food association and food choice, and the results reported by Kuchinke and colleagues (2015), exploring how EC may strengthen specifically the associations between food (CSs) and semantic information representing socio-psychological constructs (USs, i.e., words like healthiness, pleasantness, etc.) becomes particularly timely and important. Moreover, using a semantic congruency task along with EEG as pre- and post-conditioned measurement may provide valuable insights into our understanding of the neural underpinnings of the effect of EC in changing food associations.

Finally, considering the ultimate goal of changing food choice in order to improve dietary behavior, it is very important to examine the effect of EC as well as its neural correlates in individuals with different food-choice related characteristics (e.g., impulsive traits). Well-documented in the literature, many health-related problems, including unhealthy dieting patterns or food choices, can be framed as a conflict between immediate, implicit impulsive responses (e.g., trait of impulsivity) and deliberated, explicit decision-making processes (Carver, 2005; Hofmann, Friese, & Wiers, 2008). Since the behavioral outcome of impulsivity toward food can be rooted in the interaction of implicit and explicit associations between food and food-related information (Brunstrom, Downes, & Higgs, 2001; Carbine et al., 2017; Hoefling & Strack, 2008; Houben, Havermans, & Wiers, 2010; Roefs et al., 2011; Watson & Garvey, 2013), EC might be also effective in improving impulsive food choice (Haynes, Kemps, & Moffitt, 2015; Zhou, Liu, Du, & Chen, 2018). It is needed to further investigate whether EC can directly and effectively change people's food choice corresponding to individual difference of impulsive trait.

1.6 Motives and objective of the present PhD project

Based on the literature reviewed above, with the present thesis I aim at achieving four main goals with the attempt to fill the gaps just outlined. In *Chapter 2*, for Study 1, I will present two experiments. Experiment 1 addresses the first aim, namely, to understand how socio-psychological constructs affect cognitive processes (e.g., implicit and explicit associations) underlying food choices and dieting habits. Experiment 1 investigates how different social factors (e.g., valence, social status, hedonic pleasure/health concern, and efficiency) are explicitly/implicitly associated to Tea and/or Coffee and how explicit/implicit associations guide our choices in different daily-life situations. Experiment 2 builds on the results of Experiment 1 in order to achieve the second aim. The *second* aim is to investigate whether the associations between food and food-related semantic information (e.g., words representing socio-psychological factors) can be changed through a classical evaluative conditioning paradigm. By using EC paradigm, the association between food and specific food-related socio-psychological information (i.e., words representing high or low social status) was manipulated. Experiment 2 also tries to test a possible strategy of intervention able to promote changes in food choices. Measurements on implicit and explicit associations were applied to quantify the effect of EC as they are important determinants of food choices. In these experiments, Coffee and Tea were selected as targets because people's preference for them is explicitly distinguishable but may be implicitly different, and may differ across daily-life contexts. For example, a person might explicitly consider Tea as a healthier drink than Coffee because of the information from mass media or because of general opinion. However, implicitly, he or she might associate Tea to health to same degree than Coffee.

In *Chapter 3* I pursue the third aim of the thesis, which is to identify the neural mechanisms underlying the change in associations between food (i.e., minimally-processed and heavily-processed food) and specific socio-psychological information (i.e., healthiness and sustainability). In Study 2 I implemented the EEG technique by targeting two well-known event-related potentials: the N400 that is held to reflect the integration of conflicting information, and the LPP that is known to differentiate levels of emotional arousal and possibly also evoked by food-related risk information (i.e., chronic disease) (Ma et al., 2014). I investigate how neural signatures track conflict between different food and related information (healthiness/sustainability). The main hypothesis is that change in the neural signature after EC should be reflected in change in food choice.

Finally, *Chapter 4* addresses the *fourth* and last aim. Following the results of Study 2 showing a more pronounced EC for individuals with higher impulsive traits, Study 3 investigates whether control of impulsivity over unhealthy food choices can be improved. Study 3 presents a variation of the EC procedure used in Study 2, namely, an evaluative priming (EP) in which participants went through a pre-EP and a post-EP Go/NoGo task combined with EEG. Two neural signatures were targeted: the P300 waveform that is elicited when food stimuli are presented, and N200 that is elicited when self-control is required. For those stimuli that were conditioned in EP, changes of P300 and N200 effects are expected for post-EP No-Go trials (i.e., food pictures as stimuli) that require self-control. This project attempts to provide a basic roadmap to the understanding of how food related information affects cognitive and neural underpinnings of food choices with the final goal to encourage healthy diets through information inputs.

CHAPTER 2

Study 1: Is coffee fancier than Tea? Changing choice of drinks by changing implicit associations between drinks and social status through evaluative conditioning.

1. Introduction

Food and drinks choices are crucial as they largely affect our health and well-being (Grunert et al., 2007). Determinants of drink/food choice have been proposed: biological (i.e., hunger, appetite, and taste), physical (i.e., access, skills of cooking, and time), psychological (i.e., mood and stress), cognitive (i.e., attitudes/preference, beliefs, and knowledge), social (i.e., culture, family, and peers), and economic determinants (i.e., cost and income) (Bellisle, 2003; Rozin, 2015). Among all the determinants, recent studies have shed light on the cognitive processes involved in drink/food perception, intake, preference, and choice (Dalenberg et al., 2014; Evers et al., 2013; Mengarelli, Spoglianti, Avenanti, & di Pellegrino, 2015; Soussignan et al., 2015; Veldhuizen et al., 2010). Specifically, evidence pointed to the possible roles of implicit and explicit associations hold about a given drink/food in determining our choice (Hollands et al., 2011; Shaw et al., 2016; Verhulst et al., 2006). In this context, most research focused on two main components affecting implicit and explicit association and in turn our choice: (i) the expected consequences of consuming the drink/food and (ii) the sensory liking (Chambers, 2014; Panza et al., 2015). However, a third component has also been suggested: (iii) social, cultural and economic context (Eertmans, Baeyens, & Van Den Bergh, 2001). Thus, the present study focuses on how explicit and implicit associations between drink/foods and psychological constructs can predict our choice and how they can be modified to change our choices.

Like food choice, drink choice is determined mostly by physiological needs. However, through the evolution of human society, drinks (i.e., Tea and Coffee) not only satisfy needs inducing physiological effects (e.g., the activating effect of caffeine), but also provide psychological benefits (i.e., feeling relax, engaging in social interactions, etc.). Tea and Coffee are two commonly consumed drinks in our daily life

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Abbreviations: Caffeine metabolism index (CMI); Implicit Association Test (IAT); Evaluative conditioning (EC); Conditioned stimulus (CS); Unconditioned stimulus (US); Body mass index (BMI); Semantic priming (SP); Visual analogue scale (VAS).

(e.g., during or after meal; during working hours or breaks) that contribute to our physical (e.g. caffeine stimulates people's cortisol secretion at rest or undergoing mental stress) and psychological well-being (e.g., drinking coffee or tea at certain context facilitates social interactions with colleagues or friends). Recent studies thus have shifted the interest to how different socio-psychological constructs affect drink choices in different daily-life contexts (Rozin, 2015). For example, a study proposed that the preferred context for having coffee differed according to physiological variables such as the rate of caffeine metabolism index (CMI). Subjects with lower CMI focused more on the social features of the coffee-drinking experience, while subjects with higher CMI found more rewarding the sensory properties of coffee (Spinelli et al., 2017). Moreover, drink choices are influenced by consumers' perception of the products that in turn is associated to demographic and psychographic factors (e.g., age, gender, household composition, country of residence, trust in sources of nutrition information, and personal values) (Thomson et al., 2017). Furthermore, the more coffee is implicitly associated with positivity the more quickly coffee pictures are approached (Genschow et al., 2013). The evidence highlighted the important role played by implicit and explicit associations between drinks and socio-psychological constructs in our daily-life choice of drinks, which also relates to the possibility to implement interventions aim at changing these associations to improve our choice.

1.1 Social and psychological constructs of interest associated to commonly consumed drinks (e.g. Tea and Coffee)

Several socio-psychological constructs could be implicitly and/or explicitly associated to commonly consumed drinks like Coffee and Tea. We selected here four constructs of interest. The *first* construct is the *social status*—a person's standing or importance in relation to other people within a society, representing by prestige of occupation, years of education, or the annual income in the case of socio-economic status (Cattell, 1942). Interestingly, people might, in fact, convey a specific image to society (i.e., prestige) by means of drink/food selection (McKenzie, 2007). People with lower socioeconomic status attempted to compensate their position by acquiring goods (i.e., drink/food) representing higher social status, providing a psychological restoration of one's standing in the social hierarchy (Mazzocco, Rucker, Galinsky, & Anderson, 2012). However, another study showed that parental socio-economic status was highly and inversely related with soft drink consumption in children (De Coen et al., 2012). Thus, the role played by the construct of social status in drink/food choice is still needed to be clarify.

The *second* construct includes two opposing ideas, namely *hedonic pleasure* and *health concern*. Subjective-reported hedonic pleasure has been shown to be important in drink/food consumption (Grabenhorst & Rolls, 2011; Kringelbach, Stein, & van Hartevelt, 2012) irrespectively if it is biologically innate or experience-based (Alba & Williams, 2013; Lee, Soto, Swim, & Bernstein, 2012). On the other hand, people seems to have ‘‘healthy = less tasty” intuition, assuming that the perceived healthiness of drink/food might affect the hedonic pleasure (i.e. tastiness) while consuming the drink/food (Huang & Wu, 2016). Thus, we considered health concern and hedonic pleasure as two opposite sides of the same coin.

The *third* construct is *efficiency*, a feature shared by both Tea and Coffee. This is based on the notion that caffeine affects people’s alertness and enhances cognitive function, especially working-memory-related network activity and connectivity (Haller et al., 2017; Schmidt et al., 2014).

The *fourth* and last construct is *valence*, a basic construct widely associated with drink/foods. For example, assessed by IAT, the implicit attitudes toward high-calorie sweet food (HCS) were positive in the healthy-weight sample and overweight groups but negative in obese participants; the reversed pattern was revealed in attitudes to high-calorie non-sweet food (HCNS). Explicitly, all participants rated HCNS significantly lower than HCS and LC foods showing how explicit and implicit attitude may not be dissociated (Czyzewska & Graham, 2008). Another study also provided evidence that adult participants showed implicit association as well as explicit association between apple and positivity, and between candy bar and negativity (Karpinski & Hilton, 2001). Also, Coca-Cola users implicitly preferred Coca-Cola over Pepsi assessed by the IAT (Maison et al., 2004). These studies pointed out that the associations between certain drink/food and valence predicted the consecutive choices. Notably, whether implicit or explicit associations predict better choice is still debated. Thus, it is important to differentiate the roles of explicit and implicit associations between drinks and constructs of interest in food choice.

1.2 Measuring implicit and explicit associations towards drinks and food

Explicit associations reflect people’s deliberative evaluations about an object (Gawronski & Bodenhausen, 2006; Petty et al., 2007), usually measured with self-report ratings or questionnaires. However, these measurements can be biased by self-presentation strategies (Egloff & Schmukle, 2003) and depends on the ability/possibility of introspection of the respondent (Verhulst et al., 2006). On the other hand, implicit associations are less susceptible to these shortcomings. Indirect measurements such as Implicit Association Test (IAT (A. G. Greenwald et al., 1998)) and the Priming Paradigm (Fazio, Sanbonmatsu, Powell, & Kardes, 1986) were developed to assess implicit associations that trigger actions or judgments, aiming at reducing the performer's awareness of the causation (A. G. Greenwald & Banaji, 1995). Notably, these techniques are valuable also for food-related associations and choices (Foroni & Rumiati, 2017; Foroni, Rumiati, Coricelli, & Ambron, 2016; Velasco, Salgado-Montejo, Marmolejo-Ramos, & Spence, 2014). Foroni and colleagues (2016) used an irrelevant distractor experiment (Ambron & Foroni, 2015) with natural and transformed food and found that individuals' IAT-score predicted the degree of motor bias display by participants for transformed food (Foroni et al., 2016). The IAT detected implicit associations between valence and specific drink/food items (e.g., juice was associated with positivity while soda was associated with negativity) as well as general categories (e.g., sweetened drinks) (Maison et al., 2001). Additionally, successful applications of priming tasks have been also reported in examining existing or newly acquired food preferences (Lamote et al., 2004; Verhulst et al., 2006). The priming paradigms (i.e., affective priming and semantic priming) measure the valenced associations to single item or category without the necessity to contrast them with an opposite item/category as in the IAT which required bipolar categories (Fazio & Olson, 2003). However, no research in the drink/food domain has included both the IAT and the Priming tasks to assess implicit associations in the same experiment that allows for comparing the predictive validity of these two assessments.

1.3 Predictive validities of implicit and explicit associations towards drink and food choices

The respective predictive validities of implicit/explicit associations in drink/food choices have been still under debate with contradictory results. Some studies concluded that both explicit and implicit associations predict behavior by explaining different portion of variance (Richetin et al., 2007; Spence & Townsend, 2007). Other evidence, instead, indicates that explicit and implicit associations interact and together determine our behavior (Maison et al., 2004). And still other research showed that implicit associations predicted only automatic behaviors while explicit ones predicted solely deliberative behaviors (Friese, Hofmann, & Wanke, 2008; Perugini, 2005). These inconsistencies have been generally explained by assuming that automatic, implicit associations are not always in line with deliberate, explicit ones (A. G. Greenwald & Banaji, 1995; Wilson et al., 2000). Considering the possible shortcomings of each measurement, including in the same experiment both explicit and implicit measurements (e.g., IAT and Priming task) would provide a solid base for disentangling whether implicit/explicit associations between drinks and socio-psychological constructs better predict our choices.

1.4 Changing the associations in order to improve drink and food choices

Implicit and explicit associations toward food, which are predominantly learned, determine drink/food choices (Rozin, 2015; Rozin & Millman, 1987). Thus, one strategy to improve drink/food choices might be through the modification of these associations. To effectively affect explicit and implicit associations toward drink/food at both single-stimulus and categorical levels, associative learning paradigm (i.e. evaluative conditioning, EC) (Bui & Fazio, 2016; Garofalo & di Pellegrino, 2017) could be a method to strengthen/weaken links between targeted stimuli/categories (the conditioned stimulus, CS) and attributes of certain socio-psychological construct (the unconditioned stimulus, US) by repeated pairing between CSs and USs (Hofmann et al., 2010). Preliminary evidence in support of this idea showed that evaluation of food (i.e. how positive/negative) can be changed by EC. Specifically, the change in implicit associations was found to mediate the change in food choice (Hollands et al., 2011; Verhulst et al., 2006) as well as drink choice and drinking habits (Shaw et al., 2016). However, the available evidence focused only on associations between drink/foods and valence. No investigation has been carried out to date in order to explore the associations between drink/foods (e.g. Tea and Coffee) and other constructs (e.g. social status) or to change these associations to influence behavioral choices.

1.5 Objectives of Study 1

Tea and Coffee as targets are particularly relevant in this context because people's implicit and explicit associations toward them are expected to be heterogeneous across individuals and clearly distinguishable, providing a basis for experimental design and manipulation. Study one comprises two experiments. In Experiment 1, we assessed both explicit (Self-report) and implicit associations (IAT and semantic priming task) and asked participants to choose between Tea and Coffee by imagining different daily-life situations to evoke different contexts of consumption (Hein, Hamid, Jaeger, & Delahunty, 2010; Hersleth, Monteleone, Segtnan, & Næs, 2015; Spinelli et al., 2017). We investigated (i) how different constructs (social status, hedonic pleasure/healthiness, efficiency, and valence) were associated with Tea/Coffee at implicit and explicit levels and (ii) whether implicit/explicit associations predict Tea/Coffee choices in different daily-life situations.

Due to limited studies which have examined how associations towards the drinks are influenced by culture (McClure et al., 2004; Verma, 2013), we could not make clear predictions on how our sample (Italian young adults) potentially possess the associations towards Tea/Coffee. What we've known is that

Coffee is considered more culturally familiar in our sample than Tea. About the predictive validity, we expected that compared to explicit associations, implicit associations should be a better predictor of drink choices in different daily-life situations (Perugini, 2005). We also examined the use of two implicit measurements within the same experiment. Based on the results from Experiment 1, in Experiment 2 we explored the possibility to change the choice of Tea and Coffee by implementing an EC procedure in a within subject design targeting the associations between Tea/Coffee and social status. We expected that EC should affect implicit associations between Tea/Coffee and the construct of social status and in turn predict the change of choices.

2. Experiment 1: Associations between Tea/Coffee and socio-psychological constructs

2.1 Methods

2.1.1 Participants and Procedure

We included twenty-two Italian young adults (12 males, mean age ± standard deviation (SD) = 23.0 ± 2.53 years, mean body mass index (BMI) ± SD = 22.8 ± 3.75) with the criteria: (a) native Italian speakers, (b) normal or corrected-to-normal vision, (c) no eating disorder accessed by Eating Disorder Inventory-3 (Garner, 2004). Participants ran the self-administered procedure individually in independent computer stations. Each participant performed 4 different IATs (A. G. Greenwald et al., 1998) and 4 different semantic priming tasks (SP) (Meyer & Schvaneveldt, 1971) in a counterbalanced order. Within either IAT or semantic priming task, the 4 tasks according to constructs of interest (social status, efficiency, hedonic pleasure/healthiness, valence) were randomized. After these tasks participants performed choice tasks for Tea/Coffee in different daily life scenarios and a questionnaire assessing demographic information as well as a rating task assessing explicit associations between Tea/Coffee and the four constructs of interest.

2.1.2 Stimuli

Stimuli consisted of 14 Coffee-related pictures and 14 Tea-related pictures as well as 14 words representing each of the 4 constructs of interest. For each construct, 7 words representing the construct (i.e., 7 words for high social status, 7 words for hedonic pleasure, 7 words for efficiency, and 7 words for positivity) and other 7 words representing each contrasted construct (i.e., low social status, healthiness, inefficiency, and negativity). The final set of stimuli was derived from a pilot study with an independent sample of 34 participants (17 males, mean age ± SD = 22.2 ± 2.08 years). Participants used a visual analogue scale (VAS) to rate how much each picture/word was associated with the construct of interest for Coffee- and Tea-related pictures and words representing 4 constructs dimension of interest: 1) social status (high and low), 2) hedonic pleasure/healthiness (pleasure and unpleasure/ healthiness/unhealthiness, 3) efficiency (efficiency and inefficiency), or 4) valence (positivity and negativity). How much aroused participants felt for each picture/word as well as how much each picture/word was related to Coffee and to Tea were also accessed.

The final set of words had a matched number of letters and frequency values. Stimuli representing each individual construct (e.g., words representing high social status and words representing low social status) were selected to significantly differ on that construct of interest (social status) but not on other dimensions (e.g., efficiency, arousal, etc.). Figure 2.1 provides examples of picture stimuli selected while Table 2.1 reports descriptive statistics of the selected picture stimuli on each dimension piloted. Table 2.2 provides examples, descriptions, and statistics for the final sets of word stimuli. All the stimuli were well-matched (ps > .05) with the exception of words representing high and low efficiency that differ in valence and arousal (ps < .05). A second exception was due to words representing positivity/negativity that differ on hedonic pleasure and efficiency (ps < .05).

2.1.3 Implicit measurements: IAT and SP

The *IAT* (A. G. Greenwald et al., 1998) was designed to measure the relative association between a target pair (here Tea/Coffee) and an attribute dimension (e.g., social status: high-low, etc.). The categories of targets included coffee-related and tea-related pictures while the attributes were words associated to one of the constructs of interest. There were 4 different IATs that were identical except for the attributes used (i.e., social status, hedonic pleasure/health concern, efficiency, valence).

Each IAT followed the traditional IAT structure with 3 classification practice blocks and 2 combined test blocks. Compatible and incompatible blocks were defined based on the combination of the target and the attribute. Compatible blocks were arbitrarily considered blocks where: (i) Coffee pictures and words representing high social status, hedonic pleasure, efficiency, and positivity, were categorized with one response key and (ii) where Tea pictures and words representing low social status, health concern, inefficiency, and negativity, were categorized with the other response key. And in incompatible blocks the response key mapping was reversed (e.g., Coffee pictures and words representing low social status shared the same response key). Response-key mapping and order of the compatible and incompatible blocks were counterbalanced across participants. The dependent variable was the IAT score expressed by Cohen's *d'* (A.G. Greenwald, Nosek, & Banaji, 2003) and was calculated separately for each IAT. Positive IAT score indicated the implicit association of Tea with high social status, hedonic pleasure, efficiency, and positivity. One-sample t-test was used to test whether each IAT score was significant different form zero that indicated a significant association between Tea/Coffee and the construct of interest.

The *SP* measures the semantic associations between a target (i.e., Tea) and a prime (words representing the constructs of interest: e.g., social status). The 4 different SPs were identical except for the type of primes based on 4 different constructs of interest. In each SP, participants went through 8 practice trials during which they received feedback. Then participants completed 2 blocks of 56 trials for each construct. In each block, there was an equal number of each type of prime-target pair (i.e., 14 positive-word/Tea picture, 14 negative-word/Tea picture, 14 positive-word/Coffee picture, and 14 negative-word/Coffee picture). Each word representing the construct was randomly associated with two tea and two coffee images. Order of trials within each block was randomized. In each trial, a fixation point appeared (2000 ms) and was replaced by a word prime representing the construct of interest (prime: 200 ms), followed by a blank screen (100ms); the target picture (Tea or Coffee) appeared and remained until response. Participants had to respond as quickly as possible whether the target picture represented Tea or Coffee. After the response, there was an inter-trial interval (500 ms) until the next trial started.

Congruent and incongruent trials were defined based on prime-target pairs. According to the definition of compatible and incompatible blocks in IAT, in SP, congruent trials were defined as: (i) target Coffee pictures were preceded by prime words representing high social status, hedonic pleasure, efficiency, and positivity and (ii) target Tea pictures were preceded by prime words representing low social status, health concern, inefficiency, and negativity. In contrast, incongruent trials were considered trials in which: (iii) target Coffee pictures were preceded by prime words representing low social status, health concern, inefficiency, and negativity and (iv) target Tea pictures were preceded by prime words representing high social status, hedonic pleasure, efficiency, and positivity. The RTs for congruent and incongruent trials were analyzed using a 2 (prime: e.g., high vs low social status words) by 2 (target: Tea vs. Coffee) ANOVA for each construct.

2.1.4 Explicit measurement

I also administered a questionnaire designed to collect the participants' demographic information (i.e., self-report social-economic status, age, gender etc.) and explicit associations of Tea and Coffee. Twenty evaluative statements related to Tea and to Coffee included five statements for each construct of interest (e.g., 'When I drink or buy Tea, it makes me look more professional and elegant'; 'I feel satisfied with drinking Tea'; 'Drinking Tea increases my risk of heart disease'; 'Drinking Tea gives me an energy boost'). Responses were provided using a 5-points Likert scale (from "1" (completely disagree) to "5" (completely agree)). The scores based on answers to statements for each construct of interest were summed up. The larger the sum, the stronger the explicit association between the target (i.e. Tea) and the construct of interest.

2.1.5 Choice Task

Participants had to choose between different Coffee and Tea items in 5 different daily-life situations, reflecting the constructs of interest and one generic shopping situation: a supermarket scenario (for all constructs of interest); an elegant restaurant setting (for social status); a situation described as if the participant was 'seeking for pleasure' (for hedonic pleasure); a situation described as if the participant was seeking healthy (for health concern); a work setting (for efficiency).

In each scenario participants were first informed about the scenario and asked if they have experienced in such situation. If not, the scenario was skipped. In each scenario participants were presented with six different items of Coffee (e.g., Espresso, Cappuccino, etc.) and 6 different items of Tea (e.g., Black Tea, Green Tea, etc.) to choose. A specific pricelists based on each scenario were provided. Participants had to indicate a first and then a second choice. Participants could also express only one choice for each scenario. Participants' total choice in a given scenario was coded as: '5' if participant chose 2 Tea products; '4' for only 1 Tea product; '3' for 1 Tea product and 1 coffee product; '2' for only 1 Coffee product; '1' for 2 Coffee products.

2.2 Results

2.2.1 Implicit measurements: IAT and SP

Figure 2.2 showed the IAT scores (in Cohen's *d'*) for each construct of interest. The result of the one-sample t-tests showed that only the IAT-effect for social status was significantly different from zero, *M*=-.19, *SD*=.36, *t*(21)=-2.46, *p*=.02. The IAT-effect for hedonic pleasure/healthiness showed a trend towards significance (*M*=.11, *SD*=.27, *t*(21)=1.98, *p*=.06). The IAT-effect for efficiency (*M*=-.08, *SD*=.44, *t*(21)=-.84) and of valence (*M*=.04, *SD*=.43, *t*(21)=.40) were not significantly different from zero (*ps* >.41). The positive IAT-effect indicates that Tea is associated with high social status, hedonic pleasure, efficiency, and positivity. Negative values indicate that Tea is associated with low social status, healthiness, inefficiency, and negativity.

Analyses were based on the sample of 21 participants due to missing data for one participant. Paralleled the IAT score, we calculated a SP score for each construct of interest. First, the RTs of congruent trials were subtracted from incongruent trials separately for Tea and Coffee. Then the subtraction for Coffee and for Tea were added. The positive SP score indicates that Tea is associated with high social status, hedonic pleasure, efficiency, and positivity. Negative values indicate that Tea is associated with low social status, healthiness, inefficiency, and negativity. The SP scores were tested against zero to see whether the associations were significant. Result from the one-sample t-tests showed that the SP score for social status (*M*= -8.70, *SD*=.46.48, *t*(20)= -.86), the SP score for hedonic pleasure/healthiness (*M*= 4.42, *SD*= 32.49, *t*(20)= .62), the SP score for efficiency (*M*= -9.73, *SD*= 45.50, *t*(20)= -.98), and the SP score of valence (*M*= -5.25, *SD*= 40.34, *t*(20)= -.60) were not significantly different from zero (*p*s >.34). In brief, there were no significant associations between constructs of interest and Tea/Coffee, even though generally the pattern of data parallels the one shown by the IAT scores.

We also tested the priming effect (RT difference between congruent and incongruent trials) for each construct of interest by separate ANOVAs: 2 Trial type (congruent vs incongruent) x 2 Drinks (Coffee vs Tea). No main effects or interactions were significant.

2.2.2 Explicit measurements

There were twenty evaluative statements related to Tea and to Coffee including five statements for the construct of interest (social status, hedonic pleasure, healthiness, and efficiency). Responses were provided using a 5-points Likert scale (from “1” [completely disagree] to “5” [completely agree]). The responses relative to each construct of interest were summed up. The higher the sum, the ‘stronger’ the explicit association between the target (i.e. Tea) and construct of interest. Here we report the mean ratings across participants based on the statement for Tea on social status (*M*= 7.00, *SD*= 2.00), hedonic pleasure (*M*= 16.00, *SD*= 3.00), healthiness (*M*= 9.00, *SD*= 2.00), and efficiency (*M*= 11.00, *SD*= 3.00).

2.2.3 Prediction of choice

We performed linear regression analyses separately for each construct to test whether implicit and/or explicit association towards Tea/Coffee predicted participants' choice of Tea/Coffee in daily-life scenarios. For every construct, the regressors were the implicit associations (either IAT or SP scores) and explicit associations (the sum of ratings on statements about either Tea or Coffee, related to each construct). The dependent variable was the number of choice of Tea/Coffee participants made in each scenario, coded from 5 to 1, with bigger numbers representing more choices of Tea. Due to the missing data, data from only 18 participants were included in linear regression analyses. As the SP scores never showed any significant relationship with the dependent variables, only the results of the regression analyses using IAT scores and explicit index as regressors were reported.

Supermarket Scenario. Implicit association between Tea/Coffee and social status significantly predicted the choice for Tea/Coffee (B=.50, t=2.18, p=.045) while the explicit associations did not (B=-.13, t=-.56, p=.587) even though the model did not reach significance levels (R^2=.24, F(2,15)=2.41, p=.12). Neither implicit nor explicit associations between Tea/Coffee and hedonic pleasure/healthiness significantly predicted drink choice. Finally, both Implicit association between Tea/Coffee and Efficiency as well as explicit association between Tea and Efficiency predicted choice (B=-.55, t=-2.27, p=.039; B=.64, t=2.66, p=.019), and the model was significant (R^2=.37, F(2,14)=4.18, p<.05).

Restaurant Scenario. Implicit associations between Tea/Coffee and social status predicted the choice for Tea/Coffee albeit only marginally significant (B=.47, t=2.03, p=.061) while the explicit associations did not (B=.07, t=.29, p=.777). The model, however, did not reach significance (R^2=.23, F(2,15)=2.24, p =.14).

Seeking pleasure Scenario. In this case explicit associations between Tea and hedonic pleasure predicted the choice of Tea/Coffee (B=.60, t=2.44, p=.029) while the implicit associations did not (B=.22, t=.91, p=.381), with a marginally significant model (R^2=.30, F(2,14)=2.98, p=.08.).

Seeking health Scenario. No significant models or predictors were found.

Work setting Scenario. No significant model or predictors were found.

2.2.4 Correlation between measurements

We investigated the correlations between IAT scores, combined-SP scores and explicit ratings within the same construct of interest. The two implicit measures show no significant correlations (p>.05).

However, IAT score and explicit associations between hedonic pleasure and Tea were negatively correlated, $r=-.51$, $p=.03$. Moreover, IAT score on efficiency was positively correlated with explicit associations between Tea and Efficiency, $r=.51$, $p=.03$.

2.3 Discussion on Experiment 1

This experiment was designed to assess implicit and explicit associations between Tea/Coffee and four constructs of interest (social status, Efficiency, Hedonic-pleasure/Healthiness, Valence) and whether these associations predict the choice of Tea/Coffee in different daily-life scenarios. Two implicit measurements were implemented: IAT and SP paradigm. The SP did not show any significant results and did not predict choice. On the other hand, at the group level, there were significant implicit associations between Coffee and high social status and Tea and low social status as indicated by the IAT score. There were also marginally significant implicit associations between Coffee and healthiness and Tea and hedonic pleasure.

Implicit associations as measure by the IAT was also the only predictor of the choice of Tea/Coffee in daily-life situations. In fact, in both social status-specific scenario (restaurant) and general daily-life scenario (supermarket), the IAT score of social status predicted the number of Tea/Coffee chosen. The more participants' implicitly associated Tea with high social status, the more Tea they chose. The explicit association between Tea/Coffee and the construct of social status didn't predict the choice. Instead, explicit associations between Tea and hedonic pleasure predicted the choice of Tea/Coffee in the scenario of seeking for pleasure. The more participants explicitly associated Tea with pleasure, the more Tea they chose. Moreover, implicit and explicit associations between Tea/Coffee and efficiency predicted choice of Tea in the general daily-life scenario (supermarket) but with opposite directions. These results implied that the patterns of implicit/explicit associations between Tea/Coffee and different socio-psychological constructs could vary so as their predictive validities. However, we cannot rule out the possibility that these results were influenced by the implicit and explicit tasks having different structures. It has been shown that if the implicit and the explicit measures are structured similarly, the correlations between these two types of measurements may increase (Payne, Burkley, & Stokes, 2008). Thus, the predictive validity of the two measurements for behavioral choices could be potentially affected too (Payne, Burkley, & Stokes, 2008).

Finally, the lack of correlation between the two implicit methods and the different results obtained with IAT and Priming suggest that IAT might be better suited for assessing decision-related associations or at least might be more suitable for this kind of experimental set up looking at general target category (Tea/Coffee) rather than individual exemplars.

3. Experiment 2: Changing implicit associations between Tea and social status to influence the choice of Tea

The results of Experiment 1 suggested that our Tea/Coffee choice is at least partially related to our implicit associations between these drinks and constructs such as social status. Based on these findings, with Experiment 2 I investigated the possibility of changing drink choices by modifying the implicit associations between Tea and social status through EC.

3.1 Methods

3.1.1 Participant and Procedure

Sixty-eight healthy Italians participated in the present study (21 males, mean age=24.3 yrs., SD=3.5 yrs.) participated in the experiment. Selection strategies and exclusion criteria were the same as Experiment 1. As to the ecological validity of real-life situation and the reduction in error variance associated with individual differences, the experiment included two within-subjects conditions counterbalanced across participants. In each condition participants performed an EC task, the IAT with the construct of social status, the explicit rating on Tea and Coffee in relation to the construct of social status, and the choice task. At the end of the two conditions participants completed a questionnaire collecting demographic information.

3.1.2 Experimental Tasks

Evaluative conditioning task (EC). The task procedure was adopted from Lebens et al. (2011). Participants perform a categorization task on the computer in which a picture of Tea/Coffee (CS) appeared randomly in one of the 4 quadrants of the computer screen and participants have to indicate whether the picture appears in the top or bottom of the screen. After participants' response a word representing high or low social status (the unconditioned stimulus, US) was briefly (400 ms) presented in the same quadrant. Each trial was as follows: fixation cross (500ms), a picture of Tea or Coffee (until response), a word representing social status (400 ms), and an inter-trial interval (1500ms). In the control condition, Tea pictures (CS1) and Coffee pictures (CS2) were randomly paired with words representing high or low social status. In the experimental condition, Tea pictures (CS1) were paired with words representing high social status and Coffee pictures (CS2) with words representing low social status. The stimuli of CSs and USs were the same as the ones used in experiment 1. For the CSs, there were 2 categories of drink (Tea and Coffee). The picture stimuli in Experiment 1 (14 pictures of Tea and 14 pictures of Coffee) were split into two sets of stimuli. Seven Tea pictures and 7 Coffee pictures were used for experimental condition and the other 7 Tea pictures and 7 Coffee pictures were used for control condition. For the USs, 7 words representing high social status and 7 words representing low social status, same as in Experiment 1, were used for both conditions.

Implicit association task (IAT). The IAT with the construct of social status was as in Experiment 1.

Explicit rating. Participants rated how much they liked each picture of Tea and Coffee (explicit association with preference) and how much each picture of Tea/Coffee is related to social status (explicit association with social status). A Visual Analog Scale (VAS) was used for all these ratings. Responses were converting position on the VAS (from "I don't like it" to "I like it a lot" for explicit association with preference; from "very low" to "very high" for explicit association with social status) to a scale ranging from 0 to 100, although this was not explicitly displayed to the participants.

Behavioral choice task. Participants were asked to imagine that they had 10 euro to buy drinks. The products to choose were 12 different types of Coffee and 12 different types of Tea. Each drink costed 1 euro. Participants were instructed that they were free to select what and how many drinks they wanted to buy until the budget of 10 euro was spent.

Demographic Questionnaires. Participant' demographic information and drinking habits related to Tea and Coffee were assessed as in Experiment 1.

3.1.3 Data analyses

In order to investigate the effect of EC on the implicit associations between Tea/Coffee and social status, we computed the IAT scores as done in Experiment 1 separately for control and experimental condition, and compared them using the paired-sample t-test. To test the effect of EC on explicit associations (explicit ratings on preference and on social status) in control and in experimental condition, the 2 Condition (control vs experimental) x 2 Drinks (Coffee vs Tea) repeated measure ANOVAs was performed for each rating. To test whether change in the implicit association and/or changes in the explicit associations predicted change in Tea/Coffee choice, we applied the linear regression statistics. Lastly, we used Pearson's correlation to examine the correlation between change in implicit association and changes in explicit associations.

3.2 Results

IAT-score. A paired t-test showed that the implicit association between Tea and low social status (and between Coffee and High social status) was significantly weaker in the experimental condition compared to the control condition (M= -.05, SD=.44; M= -.18, SD=.39; t(67)=-2.13, p=.04).

Explicit ratings. The explicit association between Tea and Coffee and social status were significantly affected by condition (F(1,67)=5.00, p=.03) and differed across the target drinks (F(1,67)=58.91, p<.001). More importantly, the interaction between *condition* and *drink* was also significant (F (1,67)=11.23, p<.001; see Figure 2.3). Simple effects analyses showed that Tea was rated as higher in social status in experimental condition compared to control condition (F (1,67)=15.97, p=.00).

The explicit association with preference reported by the participants showed a significant main effect of condition (F(1,67)=10.93, p=.00) and a significant interaction between condition and target drink (F(1,67)=4.28, p=.04; Figure 2.4). The simple effects showed that participants preferred Tea over Coffee in the experimental condition, F(1,67)=5.26, p=.02. There was also a significant difference in explicit association with preference for Tea between experimental and control condition (F(1,67)=15.21, p=.00) with the higher ratings in experimental condition (Figure 2.4).

Tea/Coffee choice. A paired t-test showed no significant difference between experimental and control conditions in the number of choice of Tea and/or Coffee (M=4.44, SD=3.03; M=4.62, SD=3.07; t(67)=1.03, p=.31).

Regression analyses. Even though the choice of tea did not change significantly across the two conditions when looking at the group as a whole, we expected that the change in implicit/explicit associations would predict the change in choice of Tea at the individual level. A regression model was run with difference in implicit associations, difference in explicit association with preference, and self-report socioeconomic status as predictors of the change in choice of Tea. As expected the model turned out to be significant (R^2=.16, F(3,64)=3.91, p<.05). The difference in IAT score between conditions significantly predicted changes in choices of Tea (*B*=.27, *t*=2.33, *p*=.023), and so did socioeconomic status (*B*=-.28, *t*=-2.46, *p*=.016). The difference in explicit associations with preference for Tea between conditions did not predict changes in choices of Tea (*B*=.02, *t*=.15, *p*>.05).

3.3 Discussion on Experiment 2

The experiment implemented an EC paradigm to test whether it was possible to modify the implicit associations between Tea and social status and in turn changing the choice toward more Tea chosen. With this within-subject design, the results demonstrated that EC effectively strengthened participants' implicit and explicit associations between Tea and high social status, and significantly increased reported explicit association with preference for Tea. The sample as a whole did not show a significant change in the number of Tea chosen. However, and most importantly, at the individual level the change in implicit association predicted the change in number of Tea chosen. Participants who showed in experimental condition increased implicit associations between Tea and high social status construct chose more Tea in real-life scenario. This was not true for the change in explicit ratings. These results suggest that the implicit associations between Tea and Coffee and the construct of social status play a role in guiding our choices. By changing the implicit associations, we were also able to change individual's choice. EC with the use of the construct of social status as US might have different effects on people with different socioeconomic background.

4. General discussion of Study 1

In the present study we were interested in exploring the implicit and explicit associations between Tea and Coffee and key socio-psychological constructs. Moreover, we examined if such associations predict choice, and whether the changes of these associations could predict changes of drink choices.

The results of Experiment 1 showed that Italian young adults possessed strong implicit associations between Tea and low social status and between Coffee and high social status as measured by the IAT. Moreover, these implicit associations predicted the choice of Tea/Coffee in daily-life scenarios. In Experiment 2, we investigated the possibility to change choice of drink by changing implicit and explicit associations by implementing an EC procedure, pairing Tea pictures with words representing high social status. Through EC, implicit and explicit associations between Tea and high social status as well as explicit association with preference for Tea significantly increased. Even though the number of choice for Tea didn't change at the group level, the change in implicit associations predicted the change in choice at the individual level.

Previous research has indicated that food and drinks (i.e. Tea and Coffee) may have different imprints in different daily-life situation (Rozin, 2015; Verma, 2013). For example, Coffee consumption is considered celebratory, associated with a wealthy, refined and intellectually evolved class. Derived its utility from social role, Coffee is predominantly a drink facilitating social interaction and networking. In contrast, Tea is linked to ordinariness and is ritualistic in home consumption without being representative for social-related behaviors (Verma, 2013). Even though Verma's study (2013) is based on Asian culture - where Tea is supposedly more popular and common drink than Coffee, surprisingly, our results supported this claim and showed that also Italian young adults possessed strong implicit associations between Tea and low social status and between Coffee and high social status. This may be due to the fact that the information we receive in everyday life about Coffee still contains the representations of high social status (e.g., Nespresso machine advertisements featuring glamorous actors, Starbucks brand impression, famous elegant and antique coffee shops, etc.). Our choices may thus reflect both the actual social economic status of the individual (Mortensen, Jensen, Sanders, & Reinisch, 2001) as well as the desired lifestyle. In line with the latter idea Kim and Jang (2014) suggested that our choices may reflect status-seeking behavior, as they may be symbols of desired lifestyle. In support this claim these authors reported that young adults in South Korea pursue 'status consumption' of products/services (i.e., luxury restaurants/cafés) even though they still rely on parental financial support and limited incomes(Kim & Jang, 2014). Thus, people with lower socioeconomic status might attempt to compensate for lower social status by acquiring drink representing higher social status (Mazzocco et al., 2012).

We didn't find significant implicit associations between Tea/Coffee and other constructs of interest. This may appear surprising at first, but the limited sample of Experiment 1 could be one reason. In line with this interpretation, we did find a trend toward significance also for the IAT score for hedonic pleasure/healthiness. The IAT has been criticized for some potential limitations (e.g., Blanton, Jaccard, Gonzales, & Christie, 2006; De Houwer & Moors, 2007; Klauer, Voss, Schmitz, & Teige-Mocigemba, 2007; Wentura & Rothermund, 2007). Even though some critical concerns regarding this paradigm have been partially addressed (e.g., Lane et al., 2007; Nosek et al., 2006), yet the IAT shows serious limitations which require consideration and warrant caution in interpreting the nature of the associations assessed. The sample size of experiment 1 may have been particularly problematic for the priming paradigm that showed no significant association between Tea/Coffee and the constructs of interest. The lack of correlation between the two measures support the contention that they maybe assessing different aspects of our implicit associations (Fazio & Olson, 2003). This can be related to the potentially different mechanisms underlying the two measures. It is well-documented that the IAT seems to assess associations at the categorical level. Instead, SP accesses automatic activations within semantic network towards individual exemplars within a certain category (De Houwer, 2001; Foroni & Semin, 2012). Based on this distinction it is not surprising that the IAT-score seems to capture aspects relevant to our category-based choice task (Tea vs. Coffee). Thus, the implication and generalization of our results might be constrained by the features of IAT. More research is needed to address these issues.

EC has been recognized as an effective way to change implicit associations and/or explicit associations towards drink/foods (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). Nevertheless, the underlying mechanism by which this change occurs is still under discussion (Garofalo & di Pellegrino, 2017; Gawronski & Bodenhausen, 2006). Proposed APE model that provides an integrative explanation about patterns of association change through EC. Since both implicit and explicit associations changed correspondingly in our study, strengthened link between Tea and high social status directly influenced both associative evaluations and propositional reasoning with mutual indirect influences between the two levels (Gawronski & Bodenhausen, 2006). According to our results, the change of explicit association with preference was positively correlated with both change of explicit association social status and change of implicit association. However, there was no correlation between change of implicit association and change of explicit association with social status. Thus, in line with the APE model, a given factor (construct of high social status) may lead to changes in associative structure (change of implicit association), which is consistent with the set of subjectively valid propositions (change of explicit association with social status) considered at the moment. These provide a basis for new propositions that directly imply an evaluation of the same valence (change of explicit association with preference). Contrary to previous studies reporting EC effects only on explicit preference toward drink/foods (Lebens et al., 2011; Shaw et al., 2016), our EC manipulation successfully influenced both implicit and explicit associations toward Tea. The reason why we found changes in both implicit and explicit associations might be that EC is more effective when the link between a target (e.g. Tea/Coffee) and the construct (e.g. social status) is not salient or obvious. Thus, it reduced the possibility that participants' only change responses explicitly due to social desirability. For example, the link between high-calorie food and the construct of unhealthiness is salient and the preference toward high-calorie food is usually not encouraged. Thus, in previous studies that applied EC to change the associations between food and the construct of healthiness, change of explicit associations but not implicit associations might be due to the reaction to social desirability. Another explanation can be that EC is more effective in changing implicit/explicit associations toward the target drink/food (e.g. Tea) category that are not predominantly associated with certain construct (e.g. social status). For example, even though a bottle of juice from the vending machine contains the same amount of sugar and even more calories than soda drinks (Bates et al., 2014b), people still have strong associations between juice and the construct of healthiness. In this case, it could be potentially more difficult to change the associations through EC.

In the domain of food choice and food-related behaviors has been associated to explicit as well as implicit associations (Foroni et al., 2016). Here we found that implicit associations had consistently better predict Tea/Coffee choices compared to explicit associations. Moreover, the change in implicit associations after EC manipulation also predicts the change in participants' choices. These results are in line with previous studies supporting a predictive validity of implicit attitude toward food (Bui & Fazio, 2016; Czyzewska & Graham, 2008; Eertmans et al., 2001; Houben & Wiers, 2008).

5. Conclusion of Study 1

To conclude, through an EC procedure, both implicit associations and explicit associations between drinks (i.e., Tea) and the socio-psychological constructs (i.e., social status) were strengthened. We confirmed that implicit associations better predicted drink choice and at individual level, the change obtained via EC procedure predicted change in choice. These results provided potentially interesting avenue of research as well as intervention to modify and improve food/drinks choices and possibly can be applied to individuals with eating disorders.

CHAPTER 3

Study 2: Change your mind before you choose! Neural correlates of changing food associations.

1. Introduction

Food choice has a huge impact on our health condition and life-long well-being. Due to industrialized and urbanized living style nowadays, processed food has been easily accessible while consumptions of more natural food decreased (McMichael, Powles, Butler, & Uauy, 2007). It is well recognized that the current widespread of obesity and related chronic diseases are the results of increasing consumption of Heavily-Processed food (HP-food; i.e., ready-to-eat frozen dinners, potato chips, sweetened snacks) instead of Minimally-Processed food (MP-food; i.e., cut fruit, boiled vegetable, roasted chicken, etc.) (World Health Organization, 2003). According to the report of World Health Organization, 13% of world's adult population, which is equal to 1.9 billion people, were obese in 2014. The imbalance between energy intake and energy expenditure, which depends largely on food choice and eating habits, results in increasing risks of obesity and other chronic disease (i.e., cardiovascular disease and diabetes) (World HealthOrganization, 2003).

1.1 Processed food and its role in the diets

Ideally, healthy diets should consist mostly of natural food which is thought to be nutritious with higher values of vitamins, minerals, fibers, and sufficient amount of fats and proteins. However, in the modern society surrounded by convenient access of processed food rather than natural food, what is not sufficiently considered is how to include processed food in our diets in a healthier way. Although people are always encouraged to consume more natural food, not all types of processed food are unhealthy and this distinction should not be overlooked (Rickman, Barrett, & Bruhn, 2007).

Processed food is food altered with any deliberate change before being eaten, ranging from MP-food to HP-food (Duyff, 2017; Jones & Clemens, 2017). HP-food usually contains added sweeteners, saturated fats, artificial colors, excessive sodium, and preservatives (i.e., pre-prepared meals such as frozen pizza and microwave meals, meat products such as nuggets and hot dogs, refined starch products such as white breads and white pasta, snacks such as potato chips, sweetened confectionery) (Monteiro, 2009). MP-food, instead, goes through less industrial process which does not change much the ingredient properties and original nutrition value, such as frozen and pre-cut vegetables or fruit (i.e., bagged carrots, chopped apples), whole grains starch products, canned legumes and beans, boiled or roasted fresh meat, etc. (Monteiro, 2009).

While HP-food is considered unhealthy due to its relation to obesity, hypertension, diabetes, cardiovascular diseases, cancer, and other chronic diseases (Bates et al., 2014a), consumption of MP-food can be considered as a healthier diet (Rickman et al., 2007). Over-consumption of HP-food not only causes reduction of nutrition value of food and increases risks for aforementioned diseases but also results in excessive use of natural resources (i.e., energy needed for industrial processing) (Bates et al., 2014a). Considering the growth of HP-food consumptions, the risk of having negative consequence on health as well as having negative impacts on the environment also increases (i.e., climate change, consumption of natural resources, and pollution due to the food industry) (Garnett, 2008). As to the negative consequences on health, adolescents in USA doubled their consumption of soft drinks between 1965 and 1996, whereas consumption of milk dropped by nearly 50% (Cavadini, Siega-Riz, & Popkin, 2000). This fact might contribute to the increased population that suffered from diabetes later on. As to the negative consequences on the environment, if the dietary patterns related to the HP-food remain the same, the food agriculture and food industry will be major contributors to an estimated 80 percent increase in greenhouse gas emissions by 2050 (Tilman & Clark, 2014). Thus, an alternative way to promote healthy diet and healthy food choice might be to strengthen the link between the MP-food and the concept of healthiness. Research has investigated multiple possible interventions, one of which could potentially be valuable is strengthening the link between the MP-food and concept of healthiness via semantic information inputs (i.e., words or sentences).

1.2 Changing food choice through associative learning paradigm

People's food choice can be influenced by many factors (e.g., biological, physical, psychological, cognitive determinants, and economic determinants (Bellisle, 2003). However, learned associations and beliefs between the food and its health value (i.e., nutritional values) as well as the concerns about consequence of consuming certain food (i.e., potential diseases caused by eating a certain food) have been identified as playing a major role in food choice (Hayes & Ross, 1987; Rozin & Millman, 1987). Interestingly, the associations and beliefs about food that guide our food choice are predominantly learned through experiences (Martin & Levey, 1978). Because of this feature, one could assume that the associations and beliefs about food could be changes by an appropriate and effective intervention (Capaldi, 1996). Recently, evidence has been shown that modifying the associations between a certain food/food category (e.g., MP-food) and food-related information (e.g., health claim) could be a possible intervention (Hollands et al., 2011; Lebens et al., 2011; Verhulst et al., 2006).

1.3 The associative learning paradigm: Evaluative conditioning

Evaluative conditioning (EC) is an associative learning paradigm frequently used to strengthen or weaken the association between a target stimulus and an attribute concept, by pairing the target (conditioned stimulus, CS) with a valanced concept (unconditioned stimulus, US) (i.e., word representing healthiness or unhealthiness) several times. After applying EC, changes of the target-concept associations were observed at both implicit and/or explicit level, measured by implicit (i.e., implicit association task, IAT) and explicit (i.e., explicit ratings of preference) measurements (Hofmann et al., 2010). Several studies have applied EC to investigating the possibility of changing food associations and choices. An early study proved that people's implicit associations toward snacks can be modified making snacks more negative in valence implementing EC. Moreover, in a subsequent choice-task, the EC proved to be effective in reducing the choice of snacks (Rozin & Millman, 1987).

More recently, in addition to the use of words representing positivity or negativity, studies examined whether EC can be effective in changing the associations between food and the concept of healthiness. For example, compared to the control group, participants who went through the EC procedure showed more negative implicit associations toward energy-dense snacks, especially for those who possessed more positive implicit associations toward snacks at baseline. Moreover, the same group of participants were more likely to choose fruit rather than snacks in a behavioral choice task and this choice was mediated by the changes in individuals' implicit associations (Hollands et al., 2011). Similarly, in another study, female participants were presented with several pairings of images through EC, including image of fruits paired with slim female body-figures and images of snacks paired with overweight female body-figures. Compared to participants in the control condition, participants who went through EC procedure demonstrated more negative implicit associations towards snacks. However, no change in the consequent food choice was found (Lebens et al., 2011).

In my Study 1, we adapted the EC procedure from Lebens et al. (2011) to investigate the effectiveness of the EC intervention on strengthening the associations between socio-psychological constructs (i.e., social status) and culturally-familiar drinks (i.e., Tea and Coffee). I found that Italian young adults implicitly associated Tea with low social status and Coffee with high social status. However, through EC intervention, both implicit and explicit associations between Tea and high social status were significantly strengthened. Moreover, the change in implicit associations predicted the change in choice of drink.

In the attempt to induce food (dis)likes, Verhulst et al. (2006) used an EC procedure in which they contingently paired real food items with different types of information. In one condition, food images were paired with sensory liking (i.e., actual tasting) while in another condition food images were paired with information regarding the expected consequences of eating that food. After the EC, the results of an image–image naming task demonstrated significant affective priming effects for both types of pairing. This result also suggests that food associations can be based on sensory liking or other information – in this case regarding the expected consequences of eating the food that were presented verbally. A second interesting aspect of this study is that authors also investigated whether EC-induced changes could predict subsequent behavioral choices. The results showed that only food associations affected by sensory liking predicted food-related choice (Verhulst et al., 2006).

To summarize, the EC can be an effective paradigm for changing implicit associations and/or explicit associations between a target food/food category and related concepts such as healthiness (Hofmann et al., 2010; Hollands et al., 2011). And the information based on the concept of healthiness contributes significantly to food choice (Hollands et al., 2011; Lebens et al., 2011; Verhulst et al., 2006). To date, however, the evidence about this is only based on behavioral tasks and lack of two important aspects: 1) no study has investigated what is the neural underpinning the effect of EC in food associations, and 2) the effect of EC on food choice has been investigated in experimental setting which was lack of external validity with hypothetical choices, and was distant from the normal daily life situation where we select food. In order to improve the choice by increasing the consumption of MP-food, two concepts are important, namely, the concept of healthiness and the concept of sustainability. In fact, the MP-food provides the opportunity to improve one’s own diet while also making the food-production more sustainable. Thus these two concepts can be targeted by an intervention to make the choice of MP-food more appealing and more frequent.

1.4 Neural mechanism underlying food choice and change of food choice

Even though more studies have shed light on the neural mechanism underlying food perceptions, semantics, valuations, and choice (Aiello et al., 2018; Bielser et al., 2016; Camus et al., 2009; Foroni et al., 2016; Linder et al., 2010; Nijs et al., 2008; Pergola et al., 2017; Plassmann et al., 2007; Schacht et al., 2016; Toepel et al., 2014) (for a review see also Foroni & Rumiati, 2017; Foroni et al., 2016), very few studies have explored the neural mechanisms underlying food associations and the EC effect on changing food associations and food choice (Hollands et al., 2011; Lebens et al., 2011; Verhulst et al., 2006). To our knowledge, only one study investigated the behavioral and ERPs correlates of the naturalistic appetitive conditioning (Blechert et al., 2016). In their study, a set of images of neutral geometric shapes were conditioned to marzipan taste in a single trial procedure (CS+) while another set of images of geometric objects were associated with non-edibility and plastic taste (CS-). Subjective ratings on pleasantness increased only for the CS+. Importantly, the ERP component N1 (negative waveform around 100ms after stimuli onset) in image viewing task decreased from pre- to post-conditioning for the CS+ but not for the CS−. An enhanced later ERP component LPP was found in post-conditioning image viewing task for the CS+ only. In addition, participants who reported increased state-craving during conditioning showed stronger N1 and LPP modulations. The authors concluded that the taste-appetitive conditioning can shape attentional and motivational neural processes toward food stimuli. However, still very few studies have attempted to investigate how food-related information might influence food association at neural level. Herewith I will review them.

Using EEG, Ma and colleagues (2014) investigated the neural correlates of food evaluation and how these correlates are influenced by health claims (e.g., information on diseases that could arise with food consumption). When presented with disease-related risk information, sweet-tasting food elicited in the participants more conflict than salty food as indicated by a negative ERP component between 250–500ms (i.e., N400). This study has shown how ERPs markers can successfully differentiate associations between food and related-information that can be implemented to index conflict between a given food and a certain information. (Hoogeveen et al., 2016) investigated the strength of associations with food and certain information using a semantic-congruency task with food as targets and food-related information (i.e., healthiness) as primes to index the semantic conflict elicited by different prime-target pairs. Participants performed a semantic-congruency task, in which food or non-food target images were primed with three different types of words: sensory prime like taste (i.e., sweet and salty); non-sensory primes like healthiness (i.e., healthy, unhealthy); or eating context (i.e., breakfast, dinner). The prime-target pairs could be congruent or incongruent in meaning. The authors reported a smaller N400 amplitude at the parietal regions when categorizing food as compared to non-food images, indicating more congruent associations between food-related primes and food target images, as compared to non-food target images. This effect was more prominent for trials containing word primes representing the sensory nature of food (Hoogeveen et al., 2016). The relevance of sensory associations with food has been also supported by the results of another ERPs study implementing a semantic congruency task (Pergola et al., 2017). In Pergola et al.' study, participants were presented with series of trials involving a sentence (prime) followed by an image of either natural food (e.g., cherry) or a transformed food (e.g., pizza). Primes described either a sensory feature of the food ('It tastes sweet') or a functional feature ('It is suitable for a wedding party'). Participants had to decide whether prime-food pairs were congruent or incongruent and N400-like components was investigated. Semantic processing induced significantly different N400 according to the type of food and the type of prime with larger amplitude for transformed food than for natural food when paired with sensory primes, while the opposite results was observed when paired with functional primes. These studies supported the value of using EEG markers such as N400 to investigate the associations between food and food-related information. In particular, they supported the notion that N400 can be used as a marker of the strength of associations between a targeted food (e.g., MP-food) and food-related information (e.g., healthiness) (Pergola et al., 2017). The N400 marker also seems to be appropriate because it can be elicited by the presentation of semantically unrelated or conflicted information between words, images or contexts (Kutas & Federmeier, 2011) using numerous different tasks (i.e., action sequences and pictorial stimuli such as videos, actions, and motor events or congruent–incongruent images) (Aravena et al., 2010).

1.5 Individual characteristics/eating habits and change of food associations

In understanding food choice, however, one should not overlook the possible idiosyncratic individual difference. Thus, with the aim of understanding food choice and possibly improve eating behavior, it is also important to explore whether any change in association between food and information or any change in eating choice is related to individual characteristics and individual eating habits.

It is well documented in the literature that many health-related problems, including unhealthy dieting patterns or food choices, can be framed as a conflict between immediate, implicit impulsive responses (e.g., trait of impulsivity) and deliberated, explicit decision-making processes (e.g., restrained behavior)(Carver, 2005; Friese, Hofmann, & Wanke, 2008). Previous studies have suggested that the deviant dieting behavior such as impulsivity towards food in obese individuals as well as restrained eating behavior can be related to the interaction between implicit and explicit associations between food and food-related information (Brunstrom et al., 2001; Carbine et al., 2017; Hoefling & Strack, 2008; Houben et al., 2010; Lebens et al., 2011; Watson & Garvey, 2013). Since EC has been proved to be effective in changing food-related associations and food choice, the effect of EC might be related to individuals' impulsive characteristic and restrained eating behavior. These two dimensions that have received increasing attention are the individual's impulsivity and individual degree of restraining eating behavior (i.e., impulsive behavior and restrained eating behavior). Restrained eaters tend to limit food intake in order to prevent weight gain or to promote weight loss and have higher risk of engaging in binge eating (Herman & Mack, 1975). Common characteristics of restrained eaters include self-weighing, excessive fear of weight gain, frequent dieting, counting calories, guilt after eating, labelling foods as "good" or "bad", food avoidance, and the difficulty of going on diet once going off it (Fedoroff, Polivy, & Herman, 1997; Heatherton, Herman, Polivy, King, & McGree, 1988). Indeed, recent studies suggested that restrained eaters demonstrated stronger response to attractive food cues by eating more while unrestrained eaters showed less responsiveness. Moreover, food–related information inputs differentially influence the eating behavior in restrained and unrestrained eaters. For example, labeling a food as healthy encouraged more eating by restrained eaters. Also, diet-priming cues reduced the consumption of food in restrained eaters even in the face of attractive food cues (Polivy & Herman, 2017).

In the domain of food-related perception and behavior, the concept of impulsivity has been of interest as difference in impulsive characteristics not only is associated to food choice but co-varies with eating disorders. It has been reported that obese individuals who were scored higher in impulsive characteristic showed more impulsivity towards food stimuli and were worse in performing tasks assessing inhibitory control (i.e., Go/noGo task) (Bartholdy, Dalton, O'Daly, Campbell, & Schmidt, 2016; Lavagnino, Arnone, Cao, Soares, & Selvaraj, 2016). A meta-analysis study summarizing inhibitory control performance in obese individuals with and without binge eating disorder concluded that the impairment in inhibitory control is a critical feature associated with obesity but is independent of the presence of binge eating disorder (Lavagnino et al., 2016)

More generally, impulsivity has been defined as a multifaceted characteristic and as the tendency to taking action without thinking (i.e., motor impulsiveness), the difficulty in paying attention or concentrating (i.e., attentional impulsiveness), and the inability to plan beforehand (i.e., non-planning impulsiveness) (Fossati, Di Ceglie, Acquarini, & Barratt, 2001). Since both restrained eating behavior and impulsive behavior could be potential targets of clinical interventions aimed at treating patients with eating disorder, it is worth exploring whether any intervention (here EC) can be effective on changing food associations and improving food choice for restrained and /or impulsive eaters.

1.6 Objectives of Study 2

The present study aims at testing the effectiveness of an EC-based intervention in increasing the selection of MP-food and reducing the selection of HP-food as well as investigating the neural underpinning of such change. An image-word EC paradigm was implemented to attempt to strengthen the semantic associations between MP-food and the concepts of healthiness/sustainability, as well as between HP-food and the concepts of unhealthiness/unsustainability.

The implicit and explicit associations between food and the concept of healthiness/sustainability were measured after the EC-based intervention and a control condition, respectively, with the use of the Implicit Association Test (Greenwald et al., 1998) and explicit ratings of food items on relevant dimensions. Additionally, participants' food choice was also recorded after each condition implementing a behavioral choice task: the Virtual Supermarket (Waterlander, Jiang, Steenhuis, & Mhurchu, 2015). To test the neural underpinning of change of food associations through EC-based intervention, a semantic congruency task together with EEG technique was implemented targeting the ERP neural marker N400. This neural signature has been shown to track the integration of conflict (Ambron & Foroni, 2015; Pergola et al., 2017) between a food item and food-related information (i.e., healthiness). Based on this idea, a given food that is considered healthy should induce a larger N400 when presented with information related to unhealthiness (e.g., it induces a disease).

We hypothesize that a successful EC-based intervention that links HP-food and unhealthiness/unsustainability and MP-food and healthiness/sustainability should: (a) increase the explicit and implicit associations between these types of food (HP-food and MP-food) and the concept (respectively, unhealthiness/unsustainability and healthiness/sustainability); (b) increase the conflict between these types of food HP-food and information related to healthiness/sustainability and between MP-food and information related to unhealthiness/unsustainability as indexed by N400; (c) reduce the choice of HP-food and increase the choice of MP-food; and (d) produce a change in neural signature as indexed by the N400 which should correlate with individuals' traits related to dieting behavior (i.e., impulsive behavior and /or restrained eating behavior).

2. Methods

2.1 Material and Methods

2.1.1 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. Eating Disorder Inventory-3 (Garner, 2004) was used to exclude participants at risk of having eating disorder. Dietary restriction and habits were also used to exclude participants with dietary restrictions for medical, religious or personal reasons. The study was approved by the SISSA Ethics Committee and informed consent was obtained from the participants before starting the experiment. The participants were informed regarding the procedure, task, and equipment of the study. However, participants were naïve to the dimensions investigated in the study. Full disclosure was provided at the completion of the experiment through debriefing.

2.1.2 Procedure

Participants went through two separate sections individually with approximately a week of interval (Mean = 8 days, range 7 – 12 days). In each session, after providing informed consent, participants performed either the EC-based condition or the control condition. The order was counterbalanced across participants. Participants then completed the semantic congruency task with Electroencephalography (EEG). After removal of the EEG equipment, they completed the IAT (A. G. Greenwald et al., 1998), the explicit rating, and the behavioral choice task. Finally, only at the end of the session with control condition, participants completed the three questionnaires. At the end of the second session, participants were debriefed and paid for their participation.

2.1.3 Stimuli

The stimulus material for the experiment was chosen after having performed a pilot study involving an independent sample of 21 Italian healthy adults (5 males, mean age ± SD = 23.3 ± 2.46, age range 20–28, mean BMI ± SD = 21.9 ± 2.96). Participants rated 148 food images from two databases FRIDa (Foroni, Pergola, Argiris, & Rumiati, 2013), Food-pics (Blechert, Meule, Busch, & Ohla, 2014), and free sources on Internet on several characteristics: perceived calorie content, degree of processing, immediate edibility, valence, familiarity, typicality, discriminability, and arousal, using a 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 the other 20 images with low-caloric density (Figure 3.1). Information regarding the caloric density was obtained from the validated abovementioned databases.

The images were then randomly assigned into two sets of stimuli to be used in the different conditions (EC-Based condition and control). In each set, there were 10 MP-food/high-calorie images (MH), 10 MP-food/low-calorie images (ML), 10 HP-food/high-calorie images (HH), and 10 HP-food/low-calorie images (HL). The lower-level visual features (spatial frequency, brightness, and image size) were controlled across stimuli sets. Images of MP-food and HP-food were different on the degree of processing (with HP-food being higher in processing than MP-food) and were matched for the other characteristics. The only exceptions were calorie-content and valence (i.e., HP-food showed higher perceived calorie content, more negative valence). Table 3.1 depicts all the details for the comparison on these dimensions of the different categories.

Participants also rated 20 words denoting respectively each concept of interest (healthiness, unhealthiness, sustainability, and unsustainability) on arousal, relation to healthiness, relation to sustainability, and valence. Final sets of stimuli contained 10 words for each of the concept as unconditioned stimuli (USs). Words representing healthiness were more related to healthiness and rated as more positive in valence, compared to words representing unhealthiness. Words representing sustainability were more related to sustainability and rated as more positive than words representing unsustainability. The selected words were used as USs in both EC-based experimental condition and in the control condition. Table 3.2 shows the relevant information and statistics.

2.1.4 Tasks

Participants performed the Semantic congruency task, Implicit association test, explicit ratings, and the behavioral choice task twice: one after the EC-based condition and one after the control condition.

Evaluative conditioning (EC) task

The EC-based task was used in order 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. The task procedure was adapted from the study of Lebens et al. (2011). Here a food image stimulus (CS) was presented in one of the four quadrants of the computer screen. To prevent awareness of the study's purpose, the participants had to categorize the image by the spatial location instead of the content of the image. After the location of the food image was categorized by the participant, the word stimulus (US) representing the concept of healthiness/sustainability or unhealthiness/unsustainability briefly appeared in the same position as the image. In each condition, there were 10 MP-food/high-calorie images (MH), 10 MP-food/low-calorie images (ML), 10 HP-food/high-calorie images (HH), and 10 HP-food/low-calorie images (HL). In the EC-based experimental condition, images of MP-food were always paired with the words representing healthiness or sustainability, whereas images of HP-food were always paired with words representing unhealthiness or unsustainability. In the control condition, the CS–US pairings were randomized so that images of HP- or MP-food were followed by words representing either healthiness/sustainability (50% of trials) and by words representing unhealthiness/unsustainability (50% of trials). Moreover, the number of times that each paring appeared in one of the four quadrants was equal. According to the number of selected stimuli, in each condition, there were 160 trials (4 categories of food images, 10 food images in each category paired with 1 of the 10 words from each concept, 4 positions in one of the quadrants on the screen) with one time of repetition, resulting in total 320 trials.

Semantic congruency task with EEG recordings

The semantic congruency task assesses the degree of congruency between one food image item and food-related information (e.g. words representing the concept of (un)healthiness/ (un)sustainability). This task was run while electroencephalographic measurement was recorded. Trial structure (Figure 3.2) was as following: a fixation cross appeared in the center of the screen (500ms), followed by the word stimuli (prime) (800ms); then a target food image appeared in the center of the screen (1000ms). Participants needed to decide whether the concept of the word was congruent (e.g., image of dried fruit with the word "healthiness",) or incongruent (e.g., dried fruit with the word "unhealthiness") with the food image (maximum 3000ms). Inter-trial intervals were random numbers between 200-500ms. The response-key mapping was counterbalanced between participants.

In order to gain statistical power considering the signal-to-noise ratio of EEG signals, a sufficient number of trials were needed. Thus, we generated in total 4 image of the same food item: 1) the original image (e.g., dry figs), 2) the flipped original image (left-right inverted: flipped dry figs), 3) another exemplar image that represented the same food (a second different image of dry figs); 4) the flipped second image (flipped of second image). These resulted in total 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 words representing the concept of healthiness (or sustainability), or the images of HP-food appeared after the words representing the concept of unhealthiness or unsustainability. Incongruent trials were defined as trials in which the images of MP-food randomly appeared after the words representing the concept of unhealthiness/unsustainability, while the image of HP-food randomly appeared after the words representing the concept of healthiness/sustainability. Even though both congruent and incongruent trials are presented, only incongruent trials will be considered for the analyses.

During the task, participants sat in front of a computer monitor in a soundproof with soft ambient lighting room. 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 (see Biosemi website, 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).

Implicit Association Test (IAT)

To assess participants' implicit associations between different food types (MP-food and HP-food) and the concept of healthiness/sustainability (attribute), an adapted version IAT was used (A.G. Greenwald et al., 2003). Participants went through two IATs in a counterbalanced order: one with words representing healthiness/unhealthiness as attributes (IAT-Healthiness) and the other with words representing sustainability/unsustainability as attributes (IAT-Sustainability). Both IATs consisted of 2 sessions, one for high-calorie food images and another for low-calorie food images.

Each IAT followed the traditional IAT structure with 3 classification practice blocks and 2 combined test blocks (A. G. Greenwald et al., 1998). Compatible and incompatible blocks were defined based on the combination of the target and the attribute. Compatible blocks were arbitrarily considered blocks where: (i) images of MP-food and words representing healthiness or sustainability, were categorized with one response key and (ii) images of HP-food and words representing unhealthiness or unsustainability, were categorized with the other response key. In the incompatible blocks the response-key mapping was reversed (e.g., image of MP-food and words representing unhealthiness or unsustainability shared the same response key). Response-key mapping and order of the compatible and incompatible blocks were counterbalanced across participants.

Explicit ratings

Participants rated each food image through Visual Analogue Scale (VAS), ranging from 0 to 100, although this was not explicitly displayed to the participants. There were 3 blocks of explicit ratings accessing respectively: (i) how much participants related each food image with the concept of healthiness (i.e., "How healthy or unhealthy is what is represented in the image?", ranging from "very unhealthy" to "very healthy"); (ii) how much participants related each food image with the concept of sustainability (i.e., "How sustainable or unsustainable is what is represented in the image?", ranging from "very unsustainable" to "very sustainable"); (iii) how much they like the food in the image (i.e., "How much do you like the image represented?", ranging from "I don't like it" to "I like it"). In each block, the order of presentation of stimuli was randomized. The example for each session are listed below:

Behavioral choice task

The Virtual Supermarket (Waterlander et al., 2015) was used to assess participants' food choice. The participants were given an imaginary budget of €55 for one week of food consumption. With this budget, they were asked to navigate in the virtual supermarket and choose as many food items as possible that they would like to buy among 521 products. The Dutch version was adapted and all the food items were converted from Dutch to Italian context. Each food item in the supermarket was piloted on an independent sample of 11 Italian healthy adults (6 males, mean age ± SD =28.3 ± 3.28, age range = 23-34, mean BMI ± SD =22.7 ± 2.39) that rated all products for degree of processing from 0 to 10. Then we split the items into two categories of product according to the degree of process (minimally-processed, mean degree of process ± SD= 3.6 ± 1.2; heavily-processed, mean degree of process ± SD= 6.1 ± 0.7). An Independent t-test showed that the two categories of product significantly differed from the degree of process (t (410.89) = -30.53, p = .000)

2.1.5 Questionnaires accessing individual characteristics and eating habits

Participants completed the following questionnaires.

Restraint Scale (RS)

This questionnaire (Herman & Mack, 1975) was used to assess participants' eating behaviors which focused on limiting food intake in order to either lose weight or maintain the actual body weight. Restrain Scale is divided into two subscales; The Weight Fluctuation (RS-WF) subscale measures both unsteadiness in weight and past of being over-weighted. The Concern for Dieting (RS-CD) subscale assesses concerns with food and worries about eating, and overeating propensities. The higher scores from both subscales indicate limiting the food intake than actual desired food intake.

Italian Version of Dutch Eating Behavior Questionnaire (DEBQ)

Italian version of DEBQ questionnaire (Dakanalis et al., 2013) was used to characterize the eating habits of the participants. In this questionnaire, 33 items are grouped into 3 subscales: emotional eating scale (DEBQ-EM; 13 items, e.g., "Do you have a desire to eat more when you feel lonely?"), external eating scale (DEBQ-EX; 10 items, e.g., "If foods look good and smell, do you eat more than usual?") and *restraint* scale (DEBQ-RS; 10 items, e.g., "Do you try to eat less than you would like to eat?"). Participants rated each item on a 5-point Likert scale, ranging from 1 (never) to 5 (very often). Higher scores indicated higher tendency to certain type of eating behavior: emotional, external and restrained eating behavior.

The Barratt Impulsiveness Scale-11 (BIS-11)

The Barratt Impulsiveness Scale-11 (Patton, Stanford, & Barratt, 1995) assessed 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 (Attentional, motor, and non-planning impulsivity) were also calculated separately. Patton et al. (1995) reported that the BIS-11 had high internal consistency.

2.2 Data analysis

2.2.1 Behavioral Data Analysis

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

Semantic congruency task

The analyses of the accuracy as well as the response time (RT) focused on incongruent trials. We performed a 2 (condition: EP-based vs control) x 2 (degree of process: HP-food vs MP-food) x 2 (calorie: high-calorie vs low-calorie) ANOVA based on the incongruent trials for accuracy and RT, respectively.

Implicit Association Test (IAT)

The IAT scores showed the strength of implicit association between MP-food/HP-food and the concepts of healthiness/sustainability. The dependent variable was the IAT-effect expressed by the Cohen's *d'* (A.G. Greenwald et al., 2003), and was calculated separately for the four IATs (IAT-Healthiness with high-calorie items, IAT-Healthiness with low-calorie items, IAT-Sustainability with high-calorie items, IAT-Sustainability With low-calorie items). A larger IAT-effect was held to indicate stronger implicit association between MP-food and healthiness/sustainability and between HP-food and unhealthiness/unsustainability. The IAT-effect was analyzed with a 2 (condition: EP-based vs control) x 2 (calorie: high-calorie vs low-calorie) ANOVA separately for the concept of healthiness and of sustainability.

Explicit ratings

For each dimension, the mean for each category of food images (i.e., HP-food/high-calorie, HP-food/low-calorie, MP-food/high-calorie, MP-food/low-calorie). Three 2 (condition: EP-based vs control) x 2 (degree of process: HP-food vs MP-food) x 2 (calorie: high-calorie vs low-calorie) ANOVAs were performed using the mean ratings for the dimension of liking, value of healthiness, and value of sustainability, respectively.

Behavioral choice task

Participants' behavioral choices were indexed as the number of purchased products in participants' shopping basket in each individual food category. A 2 (condition: EP-based vs control) x 2 (degree of process; HP-food vs MP-food) as well as a 2 (condition: EP-based vs control) x 2 (calorie: high-calorie vs low-calorie) ANOVAs were performed, separately, on the number of purchased products. We further calculated the differences of number of purchased products between EC-based condition and control condition for each food category as an index of changes of behavioral choice after the application of EC.

2.2.2 Event-Related Potentials (ERPs) Waveform Analyses

EEG data-analyses were performed off-line using Cartool software (http://www.fbmlab.com/cartool-download)(Brunet, Murray, & Michel, 2011).

Preprocessing at single subject level

During the offline processing, epochs were defined according to the experimental design, focusing on incongruent trials (condition × degree of process × calorie). 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 a baseline correction. EEG artifacts (i.e., eye blinks) was rejected on the basis of the method proposed by Semlitsch et al. (Semlitsch, Anderer, Schuster, & Presslich, 1986). Trials which were exceeding ±80 mV at any electrode due to the artifacts such as eye blinks, muscle potential, etc. were excluded from the averaging. 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 post-stimulus onset time in a series of pairwise comparisons (t-tests). Temporal auto-correlation at individual electrodes was corrected through the application of a 15-contiguous data-point temporal criterion (~30ms) for the persistence of differential effects. The results of this analysis are presented as an intensity plot representing time (post-stimulus onset), electrode location, and the t-test result (only p-values≤0.05 are shown) at each data point.

Group level analysis

Segments were averaged separately for each food category and in each condition, resulting in the mean voltage of each data point across trials (grand averaged). ERPs were tested through paired-sample t-test for each type of food categories (MP-food/high-calorie, MP-food/low-calorie, HP-food/high-calorie, and HP-food/low-calorie food), separately, for incongruent trials in experimental and in control conditions.

The N400 effect is usually characterized by a negative waveform between 300ms to 700ms post-stimulus onset (see Duncan et al., 2009). According to the literature, the time windows and the electrode sites reported to capture the N400 effect depend on the task and the type of stimuli. For example, the early time window around 300-500ms and the later window around 550-700ms can be defined as two subcomponents of the N400 (Duncan et al., 2009; Pergola et al., 2017). 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).

In relation to N400 topography, when the images were used as stimuli, the N400 effects were found at the more anterior brain regions (Kutas & Federmeier, 2011). In studies using food (Ma et al, 2014; Pergola et al., 2017) or non-food (Lau, Phillips, & Poeppel, 2008) stimuli in semantic congruency tasks with EEG recordings consistently showed that the N400 effect was mainly generated in left fronto-central regions. Other studies investigating the neural mechanism underlying semantic associative learning also reported the N400 in left fronto-central regions (Montoya, Larbig, Pulvermuller, Flor, & Birbaumer, 1996; Ortu, Allan, & Donaldson, 2013). Based on these studies, in our analysis we specifically focused on five electrodes in the left hemisphere, including frontal (F3, F5, F7) and central (C3, C5) regions according to the 10–20 system. Mean amplitudes of incongruent trials in 2 aforementioned time-windows of N400 effect were extracted from the selected electrodes. Then two repeated measures ANOVAs were run separately for early and later time window of N400 effect. Each ANOVA contained four factors: condition (EP-based vs control), degree of process (HP-food vs MP-food), calorie (high-calorie vs low-calorie), and electrode (F3, F5, F7, C3, C5).

2.2.3 Correlation Analyses

Correlation analyses were also performed in order to investigate the relation between the change of neural signatures (i.e., change in N400) and individuals' eating behavior and impulsive behavior accessed by the questionnaires. We calculated the difference of averaged amplitudes of ERPs for time windows of interest for HP-food and MP-food and between EP-based vs control condition as the index of changes of neural signatures. The larger amplitude of the N400, the more negative the number. In order to make the direction of correlation more immediately intuitive, the values of N400 amplitude were transformed by multiplying them by minus 1. Thus, the more positive the number, the greater the N400 effect.

3. Results

Behavioral results, EEG results, and correlation results are presented in the following sections.

3.1 Behavioral results

3.1.1 Semantic congruency task

Only the incongruent trials were analyzed. The means and SDs relative to the 2x2x2 ANOVAs on accuracy and RTs are reported in Table 3.3 and Figure 3.3.

When looking at accuracy, the main effect of calorie was significant indicating a generally higher accuracy for Low-Calorie food, F (1, 17) = 8.75, p =.009. There were three significant two-way interactions. Firstly, the interaction between condition and degree of process was also significant, F (1, 17) = 5.10, p = .037. The simple-simple main effect showed that the accuracy for MP-food was higher in experimental than in control condition, F (1, 34) = 4.95, p =.033. Also, the accuracy for MP-food was higher than for HP-food in the EC-based condition, F (1, 34) = 6.53, p =.015. Secondly, the interaction between condition and calorie was significant, F (1, 17) = 16.85, p = .001. The simple-simple main effect showed that the accuracy for Low-Calorie food was higher in experimental than in control condition, F (1, 34) = 5.98, p =.020. Moreover, the accuracy for High-Calorie food was higher than for Low-Calorie food in control condition, F (1, 34) = 24.13, p =.000. Thirdly, the interaction between degree of process and calorie was significant, F (1, 17) = 20.72, p = .000. The simple-simple main effect showed that the accuracy for MP-food was higher than for HP-food within Low-Calorie items, F (1, 34) = 9.86, p =.004. Moreover, the accuracy for High-Calorie food was higher than for Low-calorie food within HP-food items, F (1, 34) = 29.39, p =.000.

When looking at the RTs, only the main effect of condition was significant, with RTs in the EC-based condition being in general longer than in control condition, F (1, 17) = 5.58, p = .030.

3.1.2 Implicit Association Test (IAT)

The means and SDs for the 2x2 ANOVA on IAT-effect (expressed in *Cohen's d'*) are reported in Table 3.4.

When looking at the implicit associations with the concept of health, only the main effect of condition was significant for the association with the concept of healthiness, F (1, 17) = 8.54, p = .010. The IAT-effect was significantly larger after EP-based condition (mean= .77, SD= .36) than control condition (mean= .53, SD= .35), showing the strengthening of implicit associations between MP-food and healthiness as well as between HP-food and t unhealthiness after EC. There were no significant differences in regard to the implicit associations with sustainability.

3.1.3 Explicit ratings

Three 2x2x2 ANOVAs were performed on the mean ratings for each category of food images relative to healthiness value, sustainability value, and preference respectively. Table 3.3 presents means and SDs.

When looking at healthiness (Figure 3.4), the main effects of condition, degree of process, and calorie, were all significant. Generally, ratings in EC-based condition, for MP-food, and for Low-Calorie food, were higher (F (1, 17) = 7.74, F (1, 17) = 191.11, F (1, 17) = 30.93, Ps < .05). Firstly, the interaction between condition and degree of process was significant, F (1, 17) = 5.11, p = .037. The simple-simple main effect showed that the ratings on healthiness for MP-food was higher in experimental than in control condition, F (1, 34) = 12.62, p =.001. Moreover, the ratings for MP-food was higher than for HP-food in both experimental and control conditions, F (1, 34) = 187.49, p =.000 and F (1, 34) = 144.90, p =.000. Secondly, the interaction between condition and calorie was significant, F (1, 17) = 6.38, p = .022. The simple-simple main effect showed that the ratings on healthiness for Low-Calorie food were higher in experimental than in control condition, F (1, 34) = 13.82, p =.001. Moreover, the ratings for Low-Calorie food were higher than for High-Calorie food in experimental condition, F (1, 34) = 30.84, p =.000.

When looking at the ratings on preference, the main effects of condition, degree of process, and calorie, were all significant. Generally, ratings in EC-based condition, for MP-food, and for Low-Calorie food, were higher (F (1, 17) = 5.00, F (1, 17) = 5.28, F (1, 17) = 6.41, ps < .05). First, the interaction between condition and degree of process was also significant, F (1, 17) = 6.84, p = .018. The simple-simple main effect showed that the ratings on preference for HP-food were higher in experimental than in control condition, F (1, 34) = 11.62, p =.002. Moreover, the ratings for MP-food were higher than for HP-food in control conditions, F (1, 34) = 9.16, p =.005. Secondly, the interaction between condition and calorie was significant, F (1, 17) = 44.58, p = .000. The simple-simple main effect showed that the ratings on preference for High-Calorie food were higher in experimental than in control condition, F (1, 34) = 28.54, p =.000. Moreover, the ratings for Low-Calorie food were higher than the one for High-Calorie food in control condition, F (1, 34) = 30.73, p =.000.

No significant results were found for ratings on sustainability.

3.1.4 Behavioral choice

For the number of purchased products (Figure 3.5), the result of 2 x 2 x 2 ANOVA showed that the main effects of degree of process and calorie were significant, F (1, 17) = 50.38 and F (1, 17) = 63.95, ps = .000. In general, participants chose more MP-food and Low-calorie food across conditions. However, there was a significant interaction between degree of process and calorie, F (1, 17) = 65.88, p = .000. The simple-simple main effects indicated that participants chose more Low-Calorie than High-Calorie food within the range of MP-food, F (1, 17) = 129.01, p = .000. Moreover, participants chose more MP-food than HP-food within the range of Low-Calorie food, F (1, 17) = 109.72, p = .000.

3.2 EEG results

We performed ANOVA with factors including condition (EC-based vs control), degree of process (HP-food, MP-food), calorie (High-Calorie, Low-Calorie), and electrodes in left frontal-central regions (F3, F5, F7, C3, C5). The results of the N400 time windows of interest, namely 300ms-500ms and 550ms-700ms are reported below.

The average amplitudes of the time window from 350ms to 500ms were considered to be the measure of early N400 component. The results of ANOVA revealed a main effect for electrodes (F (4, 68) = 24.52, p = .000). The post-hoc Tukey test showed that the averaged amplitudes of 3 electrodes in left frontal region (F3, F5, F7) and of 2 electrodes in left central region (C3, C5) differed significantly ($p < .01$), with more negative amplitude in the frontal region.

The three-way interaction (condition x degree of process x electrodes) was significant (F (4, 68) = 4.42, p = .003), and the simple-simple main effects demonstrated that the averaged amplitude at electrode F7 for MP-food was significantly different between conditions (F (1, 170) = 4.28, p = .040). Moreover, the difference of averaged amplitude at electrode F5 for MP-food showed a trend of significance between conditions (F (1, 170) = 3.31, p = .070). More negative averaged amplitudes were found in EC-based condition. We also found that in EC-based condition, the averaged amplitudes of HP-food and MP-food significantly differed in both at electrode F5 and F7 (F (1, 170) = 6.16 and F (1, 170) = 4.12, $ps < .05$). More negative averaged amplitudes were found for MP-food. Figure 3.6 shows the average ERPs of both EC-based and control condition as well as the statistics (p value of paired t-test between conditions) for each of the food category (HP-food/High-Calorie, HP-food/Low-Calorie, MP-food/High-Calorie, and MP-food/Low-Calorie food) at electrode F7.

We also found N400-like negative waveforms in the time window of 550-700m (late N400-like component). The results of the ANOVA revealed a main effect for electrodes (F (4, 68) = 14.86, p = .000). The post-hoc Tukey test showed that the averaged amplitudes of electrode C3 in left central region differed significantly from electrodes in the left frontal regions (F3, F5, F7) (ps < .01), with less negative amplitude at electrode C3. Moreover, the averaged amplitudes of electrode C5 in left central region differed significantly from electrodes in the left frontal regions (F5, F7) (ps < .01), with less negative amplitude at electrode C5. Finally, the averaged amplitudes of electrode F3 differed significantly from electrode F7 in the left frontal region (p < .01), with less negative amplitude at electrode F3. The three-way interaction (condition x calorie x electrodes) was significant (F (4, 68) = 3.35, p = .015). The simple-simple main effects demonstrated that the averaged amplitude at electrode F7 for High-Calorie food was significantly different between conditions (F (1, 170) = 6.85, p = .010), with more negative amplitudes in experimental condition.

3.3 Correlations between changes of neural signatures and individual eating behaviors as well as impulsive behavior

Changes of amplitudes of ERP of interest (N400 and late N400-like component) representing sematic incongruence effect between conditions for HP-food and MP-food were correlated with individual eating habits and individual's impulsive behavior assessed by the questionnaires. There was no significant correlation between change in N400 signature and restrained eating behaviors, neither measured by the Restraint Scale nor by the DEBQ subscale assessing restrained eating. The other DEBQ subscales (measuring emotional eating behavior and external eating behavior) also did not correlate with change in neural signature.

Interestingly, there was a positive correlation between the total score of BIS-11 and the changes of N400 effect for MP-food at the electrode F5 (r = .47, p = .048). This significant correlation was mainly contributed by the significant correlation with the sub-score of non-planning impulsiveness (r = .50, p = .037) and the correlation with the sub-score of attentional impulsiveness (r = .41, p = .088). Moreover, correlations between the total score of BIS-11 and the changes of N400 effect for MP-food at electrode F3 as well as at electrode F7 showed the trends towards significance (r = .45, p = .061, and r = .45, p = .060). These two correlations are connected to the significant correlation with the sub-score of attentional impulsiveness (r = .48, p = .045) and the significant correlation with the sub-score of non-planning impulsiveness (r = .47, p = .052), respectively.

4. Discussion of Study 2

The goals of the present study were, first, to test whether we could induce and encourage food choice toward healthier and more sustainable food (i.e., MP-food) via a simple EC-based intervention by strengthening the association between MP-food and healthiness/sustainability. By implementing a semantic congruence task together with the EEG recording, the second goal was to investigate the neural markers of the EC-based effect. The third and last goal was to investigate whether changes in the neural signature are associated with the individual's characteristics in restrained eating behavior and impulsive behavior. In the following sections I will discuss the main findings in turn.

4.1 EC as an effective intervention to strengthen the association between food and related information

4.1.1 Change of semantic incongruence effect

At behavioral level, RTs in the EC-based condition were longer than in control condition, that is, there was an augmentation of the incongruence effect between MP-food and the concept of unhealthiness/unsustainability, as well as between HP-food and the concept of healthiness/sustainability after the EC-based intervention. More importantly, a higher accuracy in EC-based condition than in the control condition for MP-food as derived from the significant interaction between condition and degree of process for the accuracy in incongruent trials. This result implies that EC can be effective in changing semantic associations between food and related information, especially in strengthening the association between MP-food and the concept of healthiness/sustainability in our case.

Interestingly, we also found the significant interaction between degree of process and calorie. This might be due to the fact that predominant associations between the calorie contents of food and the concept of healthiness (i.e., Low-Calorie food is generally healthy) serve as the contextual cue, and potentially influence the newly-modified associations between the degree of process of food and the same concept. Through EC, the encoding of evaluative information (i.e., healthiness) about a target (i.e., MP-food) creates a memory trace that links them together. When this memory trace is strong enough, it will elicit an automatic evaluative response to future inputs related to the same target (i.e., other new MP-food items) that is in line with the value of the stored information (Fazio, 2007; Gawronski & Bodenhausen, 2006).

Although the context is usually considered irrelevant during the encoding of information, if it is evaluatively homogenous to the target, it will constrain the activation of evaluatively inconsistent information. The magnitude of this context effect depends on the integration of contextual cues into the representation of evaluative information which also depends on perceivers' attention to the context during encoding. The Representational Theory proposed by Gawronski et al. (2015) specified the role of contextual cues during associative learning. If perceivers pay attention to the context during learning, contextual cues will be integrated into the representation of the newly acquired information, forming *contextualized representation*. If not, contextual cues will not be integrated into the representation, thus forming *context-free representation* (Gawronski, Hu, Rydell, Vervliet, & De Houwer, 2015).

In our case, the significant correlation between the N400 effect in left DLPFC and individuals' level of impulsivity (i.e., attentional impulsiveness) might imply that when we tried to strengthen the associations between MP-food and the concept of healthiness/sustainability, participants seemed to pay attention and integrate also the contextual cues (i.e., the information about calorie which predominately exist in their semantic memory) into the representation of evaluative information (i.e., healthiness), resulting in the formation of *contextualized representation* for MP-food. Indeed, MP-food and Low-Calorie food in this case did share the same representation (i.e., healthiness). Thus, we also found that participants responded more correctly for MP-food than for HP-food within Low-Calorie items, and responded more correctly for High-Calorie food than for Low-calorie food within HP-food items. Even though we did not manipulate the associations between the calorie content of the food and the concept of healthiness through EC, we found a significant interaction between condition and calorie. The accuracy for Low-Calorie food was higher in EC-based condition than in control condition. Future studies will be needed to investigate how to change merely the association between the targeted food and related information irrespectively and beyond the influence of contextual cues or information (i.e., manipulating the role of attention).

4.1.2 Change of implicit and explicit associations between processed food and the concept of healthiness but not food choice

In line with previous studies, EC-based condition has been again shown to be an effective way to change implicit associations and/or explicit associations towards foods (Hermans et al., 2005; Hollands et al., 2011; Lebens et al., 2011; Lescelles et al., 2003; Shaw et al., 2016; Verhulst et al., 2006). Our results showed that participants' implicit association between MP-food and the concept of healthiness/sustainability as well as between HP-food and the concept of unhealthiness/unsustainability became stronger after EC-based intervention.

The effect on implicit association is paralleled by the effect found on the healthiness ratings for MP-food. Healthiness ratings on MP-food was higher in EC-based condition than in control condition, indicating that EC also successfully strengthened the explicit association between MP-food and the concept of healthiness.

However, we failed to find a significant change at the behavioral choice level. In general, participants chose more MP-food and Low-calorie food across both conditions. Moreover, the choice of processed food interacted with the content of calorie. 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. This might suggest that participants' choice still largely depended on the predominant knowledge about calorie content rather than the newly-learned associations between the degrees of processing and the concept of healthiness/sustainability. An additional limitation in this context maybe the choice task implemented as it may be less sensitive to capture possible initial and/or small behavioral tendency that one would expect right after a single short EC-based session. Further studies will be needed to examine how to maximize the effect of EC and whether the behavioral choice effect might manifest itself in a slower timescale by defining the optimized length of exposure and the time of behavioral choice assessment.

4.2 Early component of N400 effect and change of neural signature related to degree of process

We targeted N400 effects with the early time windows of interest around 300ms-500ms after the presentation of food image stimuli. Most importantly, at neural level we found that EC-based intervention effectively strengthened the semantic association between MP-food and the concept of healthiness/sustainability, but not between HP-food and the concept of unhealthiness/unsustainability. The averaged amplitude at dorsal lateral prefrontal cortex (DLPFC, electrode F7 and F5) for MP-food was more negative in EC-based condition than in control condition.

Though N400 effect was first discovered and well-documented in the field of lexical and semantic research (Kutas & Federmeier, 2011; Lau et al., 2008), it has been used recently as the neural signature tracking congruency between food and related information. I have already mention in my thesis a few studies using the N400 in this field such as Ma et al. (2014) and Pergola et al. (2017). In line with these studies, our findings further support the notion that N400 is an excellent marker to index changes of the associations between food and food related-information.

4.3 Later component of N400 effect and change of neural signature related to calorie

We also found N400-like negative waveforms in the later time-window of 550-700m. The averaged amplitude at electrode F7 for High-Calorie food was significantly different between conditions, with more negative amplitudes in EC-based condition. Interestingly, there was a dissociation of this effect (captured by the three-way interaction between condition, calorie, and electrodes) between early and late time windows. In the early window, we found greater N400 effect for MP-food in EC-based condition at electrode F7. In the later window, we found greater N400 effect for High-Calorie food in EC-based condition at the same electrode. According to Representational Theory, when individuals are exposed to information that is evaluatively incongruent with the initially acquired information, expectancy violations trigger a search for contextual factors that may explain the observed discrepancy. As a result, these cues are integrated into a contextualized representation of the object that includes the newly acquired, counter-associated information (Gawronski et al., 2015). In our study, participants were required to decide whether MP-food/High-Calorie food is congruent with the concept of unhealthiness/unsustainability in the semantic congruence task after they just learned the association between MP-food/High-Calorie food and the concept of healthiness/sustainability through EC. However, the predominant association between unhealthiness/unsustainability and High-Calorie food (expectancy violations) may have triggered a search for contextual factors that may explain the observed discrepancy, integrating this contextual cue (i.e., calorie content) into a contextualized representation of the food that includes the newly acquired, counter-associated information. Thus, the N400 effect in the later time window might represent this process of integration of contextual information into the newly-acquired association.

This interpretation could be tested by a study in which the effect of integrating words with congruent semantic information provided by a contextual cue on the encoding of words into memory is assessed. The process of successfully encoding contextually-congruent words appeared early (around 400ms after stimulus onset); in contrast, the process of successfully encoding contextually-incongruent words occurred around 600ms after stimulus onset (Packard et al., 2016). Here, the late-N400 effect might indicate the process of integrating contextual information (i.e., calorie content) into the newly-acquired association. Even though we did not intentionally manipulate the associations between calorie content and the concept of healthiness/sustainability in EC, it is possible that the process of integrating contextual information (i.e., calorie content) also change from control condition to experimental condition. This might explain why we found also significant interaction between condition and calorie but at the same electrode site as the interaction between condition and degree of process.

4.4 The correlation between N400 effect and individuals' impulsive behavior

The change in neural signatures, that is, the effect of EC, correlated with the individuals' level of impulsive behavior but not of restrained eating behavior. This significant correlation was mainly contributed by the significant correlation with the sub-score of non-planning impulsiveness and the correlation with the sub-score of attentional impulsiveness. All these correlations suggested that participants with more attentional and/or non-planning impulsivity showed greater change of N400 effect for MP-food in the left DLPFC after EC, thus implying that the EC might be a more effective intervention for participants with higher impulsivity such as obese individuals (Aiello et al., 2018; Mengotti, Foroni, & Rumiati, 2019).

4.5 The role of left DLPFC in changing associations between food and related information

The modulation of the N400 we observed was significant at the electrode site corresponding to left DLPFC. Previous research has shown inconsistent results as to the brain regions linked with N400 effects. Whether N400 components found in central-parietal or frontal topographies share similar or different cognitive processes is still not clear (Ambron & Foroni, 2015; Bridger, Bader, Kriukova, Unger, & Mecklinger, 2012; Pergola et al., 2017; Voss & Federmeier, 2011). In our results, the main effect of electrodes showed more negative averaged amplitudes of N400 in left frontal region (F3, F5, F7) than in left central region. This was more similar to the frontal region reported by Pergola et al. (2017) and by Coricelli et al (submitted). The similarity between their task and our semantic congruence task could explain this parallel. However, our results might provide new insight into the literature on food associations because they suggest the involvement of left DLPFC in the maintenance and manipulation of information over a brief interval (i.e., working memory) and in the integration of multiple information.

The review of the extant literature suggested that DLPFC is involved in processing simple relationships between concrete properties based on the content of working memory representation (e.g., ‘do the two stimuli match in color?’). Moreover, DLPFC maintains contextual information to influence the selection of relevant representations over competitors (Badre, 2008) and plays an important role in changing representations of information in working memory or forming new representations by integrating the stimulus feature with other types of information (Courtney, 2004).

Here the significant N400 effect at early time window after EC for MP-food provides evidence in line with the idea that left DLPFC is involved in the change of representations of processed food (i.e., MP-food) by integrating the stimulus feature with newly-input information (i.e., the concept of healthiness). In addition, the significant N400 effect at later time window after EC for High-Calorie food provide evidence that left DLPFC is also involved in processing contextual information (i.e., Calorie) which may influence the process of newly-formed representations between processed food and the concepts of healthiness/unhealthiness. Finally, the changes of N400 effect for MP-food at left DLPFC also correlated with the level of non-planning impulsiveness as well as attentional impulsiveness, assessed by BIS-11 subscales. Individual with higher level of non-planning impulsiveness and/or attentional impulsiveness showed greater changes of N400 effects at left DLPFC after EC-based condition. This correlation 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 et al., 2018; Mengotti et al., 2019). Previous studies have examined the role of DLPFC in controlling goal-directed or stimuli driven attention and action towards food (Hare, Camerer, & Rangel, 2009; Hare, Malmaud, & Rangel, 2011). They used fMRI to investigate whether exogenous cues that direct attention to the healthiness of foods could improve dietary choices in non-dieting participants. Participants did make healthier choices in the presence of health cues. Moreover, activity in DLPFC modulated the activity in ventromedial prefrontal cortex which was thought to be more responsive to stimulus value signals (i.e., the healthiness of foods) in the presence of health cues. The authors concluded that providing exogenous attention cues can be an intervention to improve food choice, demonstrated by the neural mechanism underlying successful self-control (Hare, Camerer, & Rangel, 2009; Hare, Malmaud, & Rangel, 2011). However, more studies are needed to evaluate whether the EC-based intervention can be an effective way for directly improving impulsive response to food or food choice and to investigate the role that DLPFC plays in improving self-control towards food.

5. Conclusion of Study 2

All in all, to my knowledge this is the first study to investigate the neural mechanisms underlying the change of food associations and food choice by implementing EC-based procedure. Behaviorally, EC-based intervention successfully strengthened the implicit and explicit associations between MP-food and the concept of healthiness/sustainability. More importantly, the prime-target pairs of the concept of unhealthiness/unsustainability-Minimally processed food elicited greater N400 effect in left DLPFC, identifying possible neural mechanism underlying the change of food associations and suggesting the role of DLPFC in changing or forming representations by integrating the stimulus feature with other types of information. Finally, the correlation between the N400 effect in left DLPFC and individuals' level of impulsivity (i.e., attentional and non-planning impulsiveness) might implied that the EC-based interventions can be successful in improving self-control towards food for those individuals who are characterized by lower level of control/higher level of impulsiveness. Hopefully this study will trigger more investigations on the role of DLPFC and effectiveness of the EC in improving food associations and impulsivity towards food.

CHAPTER 4

Study 3: Behavioral and neural mechanism underlying improving impulsivity towards food through associative learning paradigm: an EEG study.

1. Introduction

The daily-life food choice has great impact on our physical and mental well-being and this has become an important topic of investigation. In fact, the current widespread of obesity is likely the result of increasing consumption of Heavily-Processed food (i.e., ready-to-eat frozen dinners, potato chips, sweetened snacks) instead of Minimally-Processed food (i.e., cut fruit, boiled vegetable, roasted chicken, etc.) (World Health Organization, 2003). Processed food, ranging from Minimally-Processed to Heavily-Processed food, is food altered (compared with its original state) with any deliberate change before being eaten (Duyff, 2017; Jones & Clemens, 2017). Heavily-Processed food usually contains added sweeteners, saturated fats, artificial colors, extra sodium, and preservatives, and thus has less healthy nutritional value (Monteiro, 2009). This type of food is considered unhealthy due to its association with obesity, hypertension, diabetes, cardiovascular diseases, cancer, and other chronic diseases (Bates et al., 2014a). One possible solution to ameliorate health is to improve food choice and dieting habit by encouraging the consumption of Minimally-Processed food that can be beneficial to a healthy diet and can fit the modern life-style settings (Rickman et al., 2007).

However, Heavily-Processed food often is appetizing and tempting. Thus, much of any possible regulatory behavior will require ignoring the allure of short-term temptations (Papies, Stroebe, & Aarts, 2008). Recently it has been proposed the existence of a strong link between obesity and individuals' impulsivity (Bartholdy et al., 2016; Lavagnino et al., 2016). Indeed, impulsive food intake and food choice can be a main contributor to unhealthy dieting patterns or eating disorders. *Vice versa*, self-control is known to be essential for controlling food intake and body weight (Aiello et al., 2018; Loeber et al., 2012; Lyu, Zheng, Chen, & Jackson, 2017; Price, Lee, & Higgs, 2016; Schiff et al., 2016). Therefore, it would be very important to understand the cognitive processes and neural mechanisms underlying this impulsivity in order to find the possible interventions that may reduce impulsivity towards food.

1.1 Neural mechanism underlying impulsive food choice

An increasing number of neuroimaging studies have shed light on the underlying neural mechanisms of impulsivity towards food and how self-control plays the role in controlling such impulsivity. Two types of processes of dietary self-control in controlling impulsivity towards food have been proposed. First, self-control can play the role in voluntary suppression (i.e., inhibitory control) of an appetitive response to food cues in order to override the urge for pursuing the food, assessed by intentional food craving regulation tasks. Second, self-control involves cognitive process of value modulation, in which the value of a food is reappraised or changed, indirectly influencing the appetitive response, assessed by food decision-making tasks (Han, Boachie, Garcia-Garcia, Michaud, & Dagher, 2018).

fMRI studies investigated the neural mechanisms underlying these two types of dietary self-control identified common and distinct brain regions. Overlapping brain regions were found in both types of dietary self-control, including the inferior frontal gyrus, supplementary motor area (SMA), insula and bilateral temporoparietal junction, left middle frontal gyrus, and right putamen (Han et al., 2018). However, the tasks assessing inhibitory control induced greater activation bilaterally in the posterior parts of the SMA, ventrolateral prefrontal cortex, left lateral orbitofrontal cortex, anterior insula, and precentral gyrus, while the tasks assessing the value modulation elicited the activity in the dorsal lateral prefrontal cortex (DLPFC). Especially the DLPFC showed reduced activation during self-control as a function of body mass index (Han et al., 2018). In addition to the tasks assessing intentional food craving regulation and food decision-making tasks, the Go/No-go task has been commonly-used to examine dietary self-control of impulsivity towards food. It is worth mentioning that the meta-analysis performed after including the studies that used the Go/No-go task revealed very similar results (Ambron & Foroni, 2015; Batterink, Yokum, & Stice, 2010; Mengotti et al., 2019; Skunde et al., 2016).

The EEG too has frequently been used to examine the neural machinimas underlying not only food perception and food choice (Grabenhorst et al., 2013; Nijs et al., 2008; Pergola et al., 2017; Toepel et al., 2014), but also self-control toward food (i.e., assessed by Go/No-Go task) (Teslovich et al., 2014). Two ERP components have been observed when participants performed Go/No-Go task with food images, namely, P300 (a positive waveform around 300ms after stimulus onset) and N200 (a negative waveform around 200ms after stimulus onset). Watson and Garvey (2013) have reported that for the No-Go trials (i.e., requiring inhibitory control toward the target stimuli), compared to non-food images, food images elicited larger P300 and slow-wave responses in healthy participants, indicating the neural signature representing inhibitory control toward the salience of food stimuli. On the other hand, the N200 indicated inhibitory control and the authors reported that food images elicited larger N200, compared to non-food images, and it was positively correlated with female participants' BMIs. Specifically, an attenuated inhibitory control was associated with higher BMI (Watson & Garvey, 2013).

Carbine et al. (2017) further examined the role of self-control in response to different types of food (i.e., high- and low-calorie food) and the related food intake. When involving high-calorie food, the No-Go trials showed higher accuracy but slower response time than low-calorie food No-Go trials. In these trials compared with Go-trials was also present an enhanced inhibiting responses toward high-calorie food, indexed by a larger N200 amplitude. Interestingly, the greater the N200 the less calorie and less carbohydrate food were consumed, demonstrating that increased inhibitory control for high-calorie foods play a role on regulation of food consumption (Carbine et al., 2017).

Taken together these studies emphasize the important role of self-control in impulsivity towards food. The accumulated evidence showed that P300 and N200 can be used as neural signature tracking self-control toward food. However, to the best of my knowledge, no study has examined whether these neural signatures characterize the process of voluntary suppression (i.e., inhibitory control) of an appetitive response to food or the cognitive process of the modulation of food value underlying the impulsivity towards food (Han et al., 2018). Moreover, there is no study to date that examined the behavioral and neural correlates of possible interventions that can be applied in order to change the cognitive processes underlying the impulsivity toward food. For example, if the behavioral outcome of impulsivity towards food may be influenced by the cognitive process of the modulation of food value, interventions based on modifying the associations between certain food (e.g., Heavily-Processed food) and its value (e.g. unhealthiness) could be useful for improving self-control over the food.

1.2 Improving self-control toward impulsive food choice: associative learning

Many health-related problems, including unhealthy dieting patterns or food choices, can be framed as a conflict between immediate, implicit impulsive responses and deliberated, explicit decision-making processes (e.g., restrained behavior) (Carver, 2005; Friese, Hofmann, & Wanke, 2008). In their reflective-impulsive model Strack and Deutsch (2004) the possible mechanisms underlying impulsive behavior are discussed. On the one hand, there are "implicit associative clusters" stored in long-term memory, reflecting an individual's learning history. These clusters are rooted in the impulsive system, are assumed to be created or strengthened by temporal or spatial co-activation of external stimuli, affective reactions, and associated behavioral tendencies (Friese, Hofmann, & Wanke, 2008; Strack & Deutsch, 2004). The clusters make the individual ready to respond to the environment automatically, implicitly and quickly, according to one's needs and previous learning experiences (Seibt, Häfner, & Deutsch, 2007). On the other hand, self-control has evolved in order to balance the impulsivity. Self-control is instead rooted in the reflective system (Strack & Deutsch, 2004). This kind of higher-order mental operations (e.g., executive function) generates goal-directed decisions and actions by making reasoned and explicit evaluations, integrating strategic action plans, and inhibiting predominant responses (i.e., impulsivity). The comparably slow self-control process is based on deliberated thinking and value modulation with symbolic representations and information operations (Smith & DeCoster, 2000; Strack & Deutsch, 2004).

Since the behavioral outcome of impulsivity toward food can be rooted in the interaction between implicit and explicit associations between food and food-related information, associative learning paradigm (i.e., evaluative conditioning) which aims at strengthening the associations between certain food and certain information, it might be also effective in improving the control of impulsivity toward food.

Haynes et al. (2015) tested the effect of a brief evaluative conditioning intervention on the strength of the temptation experienced for unhealthy snacks and on the actual consumption of those snacks. Healthy, female participants completed an evaluative conditioning procedure pairing snacks with either positive or negative affections (between-subject design). Snack consumption and self-reported strength of experienced temptation to indulge in consumption of four snacks in a taste-test. Importantly, they also performed a Stop-Signal Task measuring inhibitory control. Participants in the negative-affection pairing condition did consume less snacks and report feeling less tempted by the snacks compared to those in the condition pairing snacks with positivity. Nevertheless, evaluative conditioning was only effective for individuals with low inhibitory control. The authors claimed that evaluative conditioning is useful to reduce temptation and consumption of unhealthy snacks, especially in individuals with low inhibitory control (Haynes et al., 2015). Indeed, reactivity to food cue can be the result of appetitive Pavlovian learning so conditioning paradigm can be used in the "treatment" of substance abuse and eating disorders. If this is the case then conditioning could affect particularly for those individuals with low inhibitory control (Haynes et al., 2015).

Papachristou et al. (2013) used a conditioning paradigm to study the acquisition of appetitive learned-responses and the role played by impulsivity traits in appetitive learning. The authors found that conditioning paradigm was effective for the acquisition of appetitive responses. However, impulsivity traits played no role in acquiring appetitive conditioning. Therefore, how impulsivity towards food can be improved by conditioning paradigms aim at modifying the associations between certain food and its value still remains unclear. Moreover, if evaluative conditioning does successfully improve the control of impulsivity toward food, it is needed to explore the neural correlate of such effect (Papachristou, Nederkoorn, Beunen, & Jansen, 2013).

In evaluative conditioning paradigms, the valenced unconditioned stimulus (US) typically follows the initially neutral conditioned stimulus (CS). Through multiple pairings of the neural CS and valenced US, the CS eventually acquire the US' valence. However, there are several conditioning paradigms that could be implemented. One special case of conditioning paradigm is evaluative priming (EP) (Gibbons, Bachmann, & Stahl, 2014). The EP paradigm has been used traditionally to investigate the processing of evaluative information and how it affects subsequent information processing (Fazio et al., 1986). This paradigm normally shows that evaluative processing of the target is more effective when prime and target are congruent in valence (Klauer & Musch, 2003). The main difference between evaluative conditioning and EP is that in the former, the valenced unconditioned stimulus (US) typically follows, rather than precedes, the initially neutral conditioned stimulus (CS). By systematically pairing the prime representing a given concept (e.g. word representing the concept of healthiness) with the target (e.g. food image), the paradigm combines the feature of both priming task and conditioning paradigm. In addition, this paradigm allows for the immediate measurement of participants' judgment after each prime-target pair by rating on the target. Thus, the cognitive process during associative learning can be assessed more easily (Gibbons et al., 2014; Herring et al., 2013).

1.3 Objectives of Study 3

The present study aimed at investigating whether the self-control toward food stimuli can be improved through the EP. We assumed that the impulsivity towards food is largely influenced by the modulation of food value. Thus, interventions based on modifying the associations between certain food (e.g., Heavily-Processed food) and its value (e.g. unhealthiness) could be useful for improving self-control over the food (e.g. associative learning paradigm such as EP). The EP allowed us to examine whether the associations between target food images (Minimally-Processed/Heavily-Processed food) and the concept of healthiness/unhealthiness can be strengthened during a short intervention with the immediate assessment of participants' self-report liking on the food (Gibbons et al., 2014) We investigated whether participants' self-control toward certain food (e.g., Heavily-Processed food) can be improved by strengthening the associations between food and related information (e.g., unhealthiness). EEG recordings was used to investigate the neural signature of the self-control towards two sets of food (with and without evaluative priming) and non-food targets. Based on the literature, we focused on two neural signatures: P300 waveform that is elicited when food stimuli are presented and N200 that is elicited when inhibitory control is required. We hypothesized that for those stimuli (i.e., food images) conditioned in the evaluative block in the EP, significant P300 and N200 effects are expected for post-EP No-Go trials due to the strengthened associations between specific prime (i.e., words representing the concept of unhealthiness) and target (i.e., Heavily-Processed food), demonstrating the improvement of self-control.

Participants went through an EP task where in an evaluative block (E-block) a set of images of Minimally-processed food are always primed by words representing the concept of healthiness and a set of images of Heavily-processed food are always primed by words representing the concept of unhealthiness. In a second block (control-block), a different set of Minimally-processed and Heavily-processed food images are randomly primed by words representing the concept of healthiness or unhealthiness. In addition, participants performed a Go/NoGo task with EEG recording before and after the EP implementing as stimuli the images of Heavily-processed food and Minimally-processed food.

By comparing the change of behavioral indexes (i.e. accuracy, response time, and choice of food items) and the neural signatures from pre-EP Go/NoGo to post-EP Go/NoGo, we will test the effectiveness of associative learning paradigm in improving self-control towards unhealthy food (i.e., Heavily-processed food).

2. Methods

2.1 Material and Methods

2.1.1 Participants

Fifteen Italian healthy adults (4 males, age range 19-33, mean age ± SD = 23.8 ± 3.88, mean BMI ± SD = 21.71 ± 2.37) with normal or corrected-to-normal vision participated in this study. Eating Disorder

Inventory-3 (Garner, 2004) was used to exclude participants at risk of having eating disorder. Dietary restriction and habits were also used to exclude participants with dietary restrictions for medical, religious or personal reasons. The study was approved by the SISSA Ethics Committee and informed consent was obtained from the participants before starting the experiment. The participants were informed regarding the procedure, task, and equipment of the study. However, participants were naïve to the dimensions investigated in the study. Full disclosure was provided to participants at the completion of the experiment through debriefing.

2.1.2 Procedure

Participants were tested individually. A within-subject design of experimental procedure was applied. After signing consent they went through a Go/NoGo task (GNG) while EEG was recorded (Carbine et al., 2017). Participants went through the evaluative priming task (EP) including two counterbalanced blocks (E-block and Control-block) with 2 different sets of prime-target pairs. For the E-block, images of Minimally-Processed food were primed by words representing the concept of healthiness while images of Heavily-Processed food were primed by words representing the concept of unhealthiness. For the control blocks, a second set of images of Minimally- and Heavily-Processed food were randomly primed by words representing the concept of healthiness or unhealthiness. In each trial, after the presentation of the target food image, participants immediately rated how much they like it. After EP task, participants went through again the Go/NoGo task (GNG) while EEG was recorded (Carbine et al., 2017). At the end of the experiment, participants filled in the questionnaire of The Barratt Impulsiveness Scale-11 (BIS-11) (Patton et al., 1995) which assessed the individual impulsive behaviors.

2.1.3 Stimuli

Stimulus set was obtained through a pilot study implementing a separate sample of twenty-one Italian healthy adults (5 males, mean age ± SD = 23.3 ± 2.46, age range 20–28, mean BMI ± SD = 21.9 ± 2.96). Participants rated 148 food images obtained from FRIDa database (Foroni et al., 2013), Food-pics database (Blechert et al., 2014) and from free sources on Internet. The pilot involved the rating of the images using a visual analogue scales (VAS) on several characteristics: perceived calorie content, degree of process, immediate edibility, valence, familiarity, typicality, discriminability, and arousal. Eventually, 32 images of heavily- processed food and 32 images of minimally-processed food were selected as target food stimuli, with 16 images in each type of processed food with a high-caloric density (kcal per 100g) and the other 16 images with low-caloric density. Information regarding the caloric density was obtained from validated databases.

Images were randomly assigned into two sets of stimuli that will be used for the evaluative priming task. Each set included: 8 Minimally-processed high-calorie food images (MH), 8 minimally-processed low-calorie food images (ML), 8 heavily-processed high-calorie food images (HH), and 8 heavily-processed low-calorie food images (HL). The two images set were matched for lower-level visual features (spatial frequency, brightness, and image size) as well as image characteristics (i.e., calorie content, degree of process, immediate edibility, valence, familiarity, typicality, discriminability, and arousal). Overall, images of Minimally- and Heavily-Processed food were matched for all the characteristics except degree of processing and calorie content and valence. Heavily-processes food had higher perceived calorie content, higher degree of process, and more negative valence. Images of high- and low-calorie food were matched for all the characteristics except actual calorie content per 100g.

Moreover, we also selected 68 images of artificial objects as non-food stimuli. The food and non-food stimuli were matched for all the above-mentioned characteristics except that food stimuli were considered more arousing but less positive. Table 4.1 provides all the details and statistics and Figure 4.1 provides examples of selected images used in EP as well as in GNG.

During the pilot, participants also rated 11 words denoting the concept of healthiness and 11 words representing the concept of unhealthiness on arousal, relation to health, relation to sustainability, and valence. Final sets of stimuli contained 8 words representing the concept of healthiness and another 8 words representing the concept of unhealthiness. Words representing healthiness were more related to the concept of healthiness and were more positive compared to words representing unhealthiness. The selected words were used as primes for both evaluative and control trials of EP task. Table 4.2 provides all the details and statistics and examples of selected words.

2.1.4 Tasks

The Evaluative Priming task and the Go/No-Go task were programed using E-Prime 2.0.

<u>*Evaluative priming (EP) task*</u>

The task procedure was adapted from the study by Gibbons and colleagues (Gibbons et al., 2014). Participants were presented with a prime word follow by a picture of food (target). A trial (see Figure 4.2) started with presentation of a white fixation cross for 1200ms in the center of the gray screen. The prime word appeared for 1200ms then replaced by the target food image for 1500 ms. Then a Visual Analogue Scale (VAS) appeared with the question at the center of the screen “How much do you like the food in the picture?”, prompting the participant to rate how much they like the food image. The VAS ranged from 0 to 100, although this was not explicitly displayed to the participants. The next trial started once the participant rated the food image or a 3000ms limit was reached. Inter-trial intervals was jittered (range: 200-500ms.).

The task comprised two blocks (counterbalanced in order across participants) using two different sets of food images as target. In the evaluative priming block (E-block), 16 Heavily-Processed food images (8 high-calorie and 8 low-calorie food) and 16 minimally-Processed food images (8 high-calorie and 8 low-calorie food) were preceded by one word representing, respectively, the concept of unhealthiness and healthiness (prime) chosen randomly from a list of 8 words for each concept. In the control-block: 16 Heavily-Processed food images (8 high-calorie and 8 low-calorie food) and 16 minimally-Processed food images (8 high-calorie and 8 low-calorie food) were preceded by one word representing either the concept of unhealthiness or healthiness (prime) chosen randomly from a list of 16 words (8 for each concept).

In each block, each prime-target pair randomly appeared twice, resulting in total 128 trials per block.

Go/NoGo (GNG) task with EEG recording

Participants performed the *Go/NoGo (GNG)* task while EEG data were recorded from their scalp (see below for data acquisition information). The task presented two counterbalanced sessions. The firsts session (i.e., Food-Go session) implemented food as go-trial stimuli and artificial objects as no-go trial stimuli and the second session (i.e., Food-NoGo session) implementing artificial objects as go-trial stimuli and food as no-go trial stimuli. In Food-NoGo session, for example, participants were instructed to respond by pressing “SPACE” button when they saw images of artificial objects (Go stimuli) and to inhibit responses when they saw images of food (NoGo stimuli). For Food-NoGo session, there were in total 8 blocks: 4 blocks with the set of food images used in E-block of evaluative priming task and the other 4 blocks with the set of food images used in control-block. For Food-Go session, there were in total 4 blocks: 2 blocks with the set of food images used in E-block and the other 2 blocks with the set of food images used in Control-block. Each block had 50 trials, 34 of which were Go trials and 16 were NoGo. In each trial, the image was presented for 1000 ms, with a random inter-trial fixation cross that varied between

1200 and 1400 ms. The order of blocks and the presentation of trials were randomized. Figure 4.3 shows trial structure and examples of trial.

During GNG tasks, the participant sat in front of a computer monitor in a soundproof and dim light room (i.e., an ambient lighting with the LED lamp). 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 (see Biosemi website, 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).

The questionnaire: The Barratt Impulsiveness Scale-11 (BIS-11)

The Barratt Impulsiveness Scale-11 (Patton et al., 1995) assessed 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 (Attentional, motor, and non-planning impulsivity) were also calculated separately. Patton et al. (1995) reported that the BIS-11 had high internal consistency.

2.2 Data analysis

2.2.1 Behavioral Data Analysis

Evaluative priming (EP) task

For the EP task, participants' ratings on how much they like the food images as well as response times were measured. We calculated averaged ratings and response times for each category of food (HH, HL, MH, ML) for E-block and for control-block. To investigate whether preceding prime can immediately influence participants' evaluations of liking on food images, we performed paired-sample t-tests on VAS rating scores as well as on average response times for 4 types of prime-target pairs between E-block and control-block: Minimally-Processed High- and Low-Calorie food primed by words representing healthiness as well as Heavily-Processed High- and Low-Calorie food primed by words representing unhealthiness.

Pre-EP and post-EP Go/NoGo

For both GNG tasks (pre and post EP-task), reaction times (RTs) and accuracy were measured. Hits rates (the ratio between the number of correct Go responses and the total number of Go trials in a given block) and false alarms rates (the ratio between the numbers of incorrect responses and the total number of NoGo trials) were calculated for each food category (Minimally-Processed High-Calorie, Minimally-Processed Low-Calorie food images, Heavily-Processed High-Calorie, and Heavily-Processed Low-Calorie food images) separately for the images used in E-block and control-block. Moreover, we are interested in the improvement of self-control toward food image with evaluative priming. Thus, we performed a three-way ANOVA based on the accuracy: 2 (time point: pre- and post-EP) x 2 (inhibitory control: Nogo and Go trials) x 3 (image category: E-block food images, control-block food images, and artificial object).

2.2.2 EEG Data Analysis

EEG data-analyses were performed off-line using Cartool software (http://www.fbmlab.com/cartool-download) (Brunet et al., 2011).

Preprocessing at single subject level

At individual level, we analyzed data from *Pre-* and *post-EP GNG tasks* separately. EEG epochs were preprocessed and analyzed in the time interval from -198 to 781ms post-stimulus onset. The pre-stimulus period (-198ms to 0ms) served as baseline correction. EEG artifacts (i.e., eye blinks) were rejected on the basis of the method proposed by Semlitsch et al. (Semlitsch et al., 1986). Trials which were exceeding ±80 mV at any electrode due to the artifacts such as eye blinks, muscle potential, etc. were excluded from the averaging. During the offline processing for each participant, Go trials as well as NoGo trials corresponding to the artificial objects and each category of food for the two set of images used in the EP-task (Minimally-Processed High-Calorie, Minimally-Processed Low-Calorie, Heavily-Processed High-calorie, and Heavily-Processed Low-Calorie food) were averaged separately. 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 post-stimulus onset time in a series of pairwise comparisons (*t*-tests). Temporal auto-correlation at individual electrodes were corrected through the application of a 15-contiguous data-point temporal criterion (~30ms) for the persistence of differential effects. The results of this analysis are presented as an intensity plot representing time (post-stimulus onset), electrode location, and the *t*-test result (only *p*-values ≤ 0.05 are shown) at each data point.

<u>*Group level analysis*</u>

ERP segments were averaged across participants separately for each category of stimuli in each type of trial (Go or NoGo) for each time point (pre- or post-EP), resulting in the mean voltage of each data point across trials and participants (grand average).

There were two time-windows of interest, N200 and P300 effects, which have been observed when the task required inhibitory control and monitoring conflicting cognitive resources, both for food (Carbine et al., 2017; Carbine et al., 2018) and non-food stimuli (Bokura, Yamaguchi, & Kobayashi, 2001; Ibanez et al., 2012). The topography of the N200 and P300 effects were reported to be in bilateral frontal-central regions. However, further examination of the topography of these effects between hemispheres might be needed. Therefore, our analysis focused specifically on 3 electrodes in the left frontal regions (F3, F5, F7) and in the symmetrical right frontal regions (F4, F6, F8) according to the 10–20 system. Mean amplitudes of for each category of stimuli in each type of trial (Go or NoGo) for each time point (pre- or post-EP) in two time-windows of interest were extracted from the selected electrodes.

Paired-sample t-tests for each category of stimuli comparing pre- and post-EP NoGo trials as well as Go trials were performed. Since we are interested in the improvement of self-control toward food image by evaluative priming, we averaged mean amplitudes for food image used in E-block, food image used in control-block, and artificial objects, regardless of degrees of processing and calories. Then two ERPs were tested through a 2 (time point: pre- and post-EP) x 2 (inhibitory control: Go and NoGo trials) x 3 (category of stimuli: E-block food images, control-block food images, and artificial object) x electrode (F3, F5, F7, F4, F6, F8) repeated measures ANOVA.

2.2.3 Correlation analysis

We performed correlation analyses in order to investigate the relation between the change of neural signatures (i.e., change in N200) and individuals' impulsive behavior assessed by the questionnaires. We calculated the difference of averaged amplitudes of ERPs for time windows of interest for food images used in E-block between pre- vs post-EP GNG tasks, especially for NoGo trials. Since the larger amplitude of N200, the more negative the number is. In order to make the direction of correlation more immediately intuitive, the values of N200 amplitude were transformed by multiplying them by minus 1. Thus, the more positive the number, the greater the N200 effect.

3. Results

3.1 Behavioral Data

3.1.1 EP task

<u>*Liking rating*</u>

The ratings on liking for Minimally-Processed Low-Calorie food used in E-block (mean ± SD = 58.13 ± 10.68) were significantly higher compared to those in control-block (mean ± SD = 50.57 ± 13.54), $t(14) = 3.96$, $p = .001$. Moreover, the ratings on liking showed a significant reduction for Heavily-Processed Low-Calorie food used in E-block (mean ± SD = 58.94 ± 16.48) compared to the control-block (mean ± SD = 63.58 ± 17.37), $t(14) = -2.13$, $p = .05$. However, ratings on liking for Minimally-Processed High-Calorie food (mean ± SD =59.65 ± 12.87 and mean ± SD =58.79 ± 10.63) and for Heavily-Processed High-Calorie food (mean ± SD = 56.43 ± 16.69 and mean ± SD = 54.83 ± 16.16) didn't show significant difference between E-block and control-block, $t(14) = .57$ and $t(14) = .57$, $ps > .050$.

<u>*Rating response Time*</u>

The difference of response times (ms) between E-block and control-block images was significant for Heavily-Processed High-Calorie food primed by words representing unhealthiness (mean ± SD = 829.71 ± 220.28 and mean ± SD = 789.15 ± 221.02, $t(14) = 2.27$, $p = .040$) with longer response times for E-block. There were no significant differences of response times (ms) between E-block and control-block for Heavily-Processed Low-Calorie food (mean ± SD = 823.64 ± 240.26 and mean ± SD = 857.93 ± 242.73, $t(14) = -1.56$, $p = .133$), as well as for Minimally-Processed High-Calorie food (mean ± SD = 807.08 ± 219.73 and mean ± SD = 808.50 ±225.63, $t(14) = -.90$, $p = .922$) and Minimally-Processed Low-Calorie food (mean ± SD = 815.53 ± 200.71 and mean ± SD = 793.69 ± 218.80, $t(14) = 1.07$, $p = .305$).

3.1.2 Pre-EP and post-EP Go/NoGo

Table 4.3 shows RT, accuracy, hits rates and false alarms rates for each category of food images used in each type of blocks during EP-task.

Accuracy

The main effect of *time point* was significant, $F(1, 14) = 7.60$, $p = .016$, with generally lower accuracy in post-EP compared to pre-EP (mean ± SD = .96 ± .042 and mean ± SD = .97 ± .031). The main effect of *inhibitory control* was also significant, $F(1, 14) = 18.61$, $p = .001$, with generally lower accuracy in NoGo trials (mean ± SD = .95 ± .043) compared to Go trials (mean ± SD = .99 ± .017). There was a significant interaction between *time point* and *inhibitory control*, $F(1, 14) = 9.89$, $p = .007$. The simple main effect showed that the accuracy for NoGo trials was significantly lower in post-EP, $F(1, 28) = 17.48$, $p = .000$. Moreover, the accuracy in the NoGo trials was always lower than in the Go trials independently of *time point* ($F(1, 28) = 6.30$ and $F(1, 28) = 27.60$, $ps < .050$). We also found a significant interaction between *inhibitory control* and *image category*, $F(1, 14) = 4.04$, $p = .029$. The simple main effect demonstrated lower accuracies in NoGo trials compared to Go trials irrespective of image categories (food E-block , food control-block, artificial objects), respectively, $F(1, 28) = 13.75$, $F(1, 28) = 23.54$, and $F(1, 28) = 4.20$, $ps < .050$. Finally, the accuracy in NoGo trials significantly differed across of the three image categories, $F(1, 28) = 4.57$, $p = .015$. A post hoc test (Tukey's test) showed that this difference was driven by significant lower accuracy for food images used in control-block in EP compared to artificial objects. No other significant effects were found.

3.2 EEG results for of Pre- and post-EP

We performed a 2 time point: pre- and post-EP) x 2 (inhibitory control: Go and NoGo trials) x 3 (category of stimuli: E-block food images, control-block food images, and artificial object) x 6 (electrodes: F3, F5, F7, F4, F6, F8) ANOVA. The results of the time windows of interest, namely 200ms-300ms for N200 and 300ms-500ms for P300 are reported below.

N200

The results of ANOVA revealed a main effect for *electrodes* ($F(5, 70) = 6.10$, $p = .000$). The post-hoc Tukey test showed that the averaged amplitudes of the electrode in right frontal region (F4, mean ± SD = -2.72 ± 4.00), significantly differed from the 3 electrodes in left frontal region (F3, F5, F7) (mean ± SD = -5.29 ± 3.61, -6.41 ± 3.68, and -5.93 ± 4.32, $ps < .01$), with more negative amplitude in the left frontal region.

The three-way interaction *time point* x *category of stimuli* x *electrodes* was significant (F (10, 140) = 2.58, p = .007). The simple-simple main effects demonstrated that the difference of averaged amplitudes at electrode F7 (left dorsal lateral prefrontal cortex, DLPFC, BA46/47) for food images used in E-block were significantly different across the two time points (F (1, 252) = 4.79, p = .029). More negative averaged amplitude was found in post-EP (mean ± SD = -6.84 ± 3.67), compared to pre-EP (mean ± SD = -5.10 ± 5.01). Moreover, the averaged amplitude at electrode F5 (left DLPFC, BA46/47) in post-EP was significantly different between the different level of *category of stimuli* (F (2, 336) = 3.41, p = .034). More negative averaged amplitude was found for food images used in E-block (mean ± SD = -7.11 ± 3.39), compared to artificial objects (mean ± SD = -6.432 ± 3.196).

Another three-way interaction *time point* x *inhibitory control* x *electrodes* was also significant (F (5, 70) = 2.58, p = .033). The simple-simple main effects demonstrated that the averaged amplitude at electrode F4 (right DLPFC, BA8) in pre-EP was significantly more negative in NoGo trials (mean ± SD= -3.18 ± 3.59) than in Go trials (mean ± SD = -1.80 ± 4.47), F (1, 168) = 9.20, p = .003. Moreover, averaged amplitudes at electrode F7 (left DLPFC, BA47/46) for Go trials were significantly was significant more negative in pre-EP GNG task (mean ± SD= -6.71 ± 4.14) than in post-EP GNG task (mean ± SD= -4.98 ± 4.51), F (1, 168) = 4.49, p = .036.

The significant three-way interactions were further analyzed by performing paired-sample t-tests (pre-EP vs post-EP) focusing on NoGo trials of E-block food images separately for different degree of process and calorie density. More negative N200 amplitude was found at electrode F7 (left DLPFC, BA47/46) in post-EP for Heavily-Processed Low-Calorie food as well as for Minimally-Processed Low-Calorie food, but not for Heavily-Processed High-Calorie food and Minimally-Processed High-Calorie food (Figure 4.4).

P300

No positive waveform were found during the time window of interest. Second, only the main effect for *category of stimuli* was significant (F (2, 28) = 56.02, p = .000). The post-hoc Tukey test showed that, in general, the averaged amplitude for E-block food images (mean ± SD= -3.97 ± 4.67) was significantly less negative than the averaged amplitudes for control-block food images (mean ± SD= -4.80 ± 4.41) as well as less negative than the averaged amplitudes for artificial objects (mean ± SD= -6.17 ± 4.55), ps <

.05. Also, the averaged amplitudes for control-block food images was significantly less negative compared to averaged amplitudes for artificial objects, $p < .05$.

3.3 Correlation between impulsive behavior and change of neural signature

We failed to find any significant correlation between individuals' impulsive behavior and the change of neural signatures (i.e., change in N200) for NoGo trials with food images used in E-block between pre- vs post-EP GNG tasks.

4. Discussion of Study 3

The present study examined weather healthy individuals' self-control toward processed food can be improved through associative learning paradigm. Specifically, an evaluative priming task (with a E-Block and a control-block) was implemented to produce associative learning to a set of food images. A Go/NoGo task was used to assess inhibitory control while EEG data were collected focusing on N200 and P300 markers. We observed a higher subjective liking of Minimally-Processed Low-Calorie food images in E-block. For GNG tasks, we did not find significant interaction between time points, inhibitory control, and category of stimuli. However, the interaction between inhibitory control and image category was significant. Regardless of time points, accuracies of the three image categories significantly differed for NoGo trials, with significant lower accuracy for food images in control block in EP than the accuracy for artificial objects. Interestingly, for the neural signature of interest, N200 effect, we found significant interaction between time points, category of stimuli, and electrodes of interest. Most importantly, averaged amplitudes at electrode F7 for food images used in E-block were more negative in post-EP than in pre-EP GNG task. Another three-way interaction between time points, inhibitory control, and electrodes of interest was significant. Significantly more negative averaged amplitude was found in NoGo trials than in Go trials at electrode F4 only in pre-EP GNG task. Finally, according to the further inspection considering also degree of process and calorie, more negative N200 amplitudes were consistently found at electrode F7 (left DLPFC, BA47/46) in post-EP GNG task for Heavily-Processed Low-Calorie food as well as for Minimally-Processed Low-Calorie food, but not for Heavily-Processed High-Calorie food and Minimally-Processed High-Calorie food. No P300 effect of interest was found.

4.1 Can EP strengthen the link between food and related concept through associative learning?

In the E-block of our EP task, we primed Minimally-Processed food with the concept of healthiness and Heavily-Processed food with the concept of unhealthiness. Interestingly, the ratings on liking significantly increased for Minimally-Processed Low-Calorie food and the ratings on liking showed a significant reduction for Heavily-Processed Low-Calorie food. The results indicate that participants' explicit, deliberated subjective liking on food images can be influenced by evaluative prime-target pairing during the experimental session. This effect was particularly pronounced for Low-Calorie food.

According to Strack & Deutsch (2004), reflective-impulsive model suggested that the behavioral output is determined by the interaction between implicit, impulsive, habitual process and explicit, reflective, goal-directed process (Seibt et al., 2007; Strack & Deutsch, 2004). If strengthening the link between a target food and a concept does change both implicit and explicit processes in the same direction, the behavioral outcome (i.e., preference ratings or choice) will also change accordingly. However, if implicit and explicit processes change in the opposite direction or if only one of them has been affected, the behavioral outcome might remain unchanged (Gawronski & Bodenhausen, 2006). Moreover, the change may vary depending also on other features like for instance the food own original intrinsic value which can counter or even prevent any priming effect if strongly-rooted. Even though High-Calorie food is generally considered unhealthy, High-Calorie food can have other values that implicitly and/or explicitly influence individual's judgment of liking (i.e., positivity and hedonic value) (Killgore & Yurgelun-Todd, 2007; Rozin & Millman, 1987), resulting in a marginal change in subjective liking.

We failed to find a priming effect on response time (RT). In the EP task, participants were fully aware of the primes (words representing the concept of healthiness or unhealthiness) and had sufficient time (i.e., 1200 ms) to engage in both implicit and explicit processing of the meanings (Wong & Root, 2003). Notably, RT is an important dependent measure in congruency-based priming paradigm but not in evaluative priming (Gibbons et al., 2014). Moreover, participants were instructed to be as accurate and fast as possible, but the setup of the task, doing the ratings only after the target had disappeared from the screen and not as soon as they were ready, may have prevented priming effects on RT from emerging (Gibbons et al., 2014).

4.2 EP as a possible intervention to improve self-control towards visual food stimuli

Behaviorally, we failed to find direct evidence that EP improved the self-control towards food images used in E-block. However, at neural level, we found a significant interaction between time points, category of stimuli, and electrodes of interest for N200 effect. Most importantly, the difference of averaged amplitudes at electrode F7 for food images with evaluative priming were more negative in post-EP than in pre-EP. The further comparison for NoGo trials between time points considering also degree of process and calorie showed that more negative N200 amplitudes were consistently found at electrode F7 (left DLPFC, BA47/46) in post-EP GNG task for Heavily-Processed Low-Calorie food as well as for Minimally-Processed Low-Calorie food, but not for Heavily-Processed High-Calorie food and Minimally-Processed High-Calorie food.

Even though we did not find a significant four-way interaction, the results suggest that the EP is a plausible intervention to improve self-control for food as demonstrated by the more negative N200 amplitude at left DLPFC for Heavily-Processed Low-Calorie food and for Minimally-Processed Low-Calorie food. Our results cannot be explained as the improvement of inhibitory control itself, as most of the previous studies showed, increased N200 effect when further inhibitory control is required (i.e., for High-Calorie food compared to Low-Calorie food or in obese compared to normal weight individuals) and reduced N200 effect when inhibitory control is better functioning (i.e., in restrained compared to non-restrained individuals) (Carbine et al., 2017; Kong, Zhang, & Chen, 2015; Watson & Garvey, 2013; Zhou et al., 2018). Instead, increased N200 effect in our study might indicate the cognitive process of modulating food value and monitoring the conflict, such as the conflict between activation of an automatic response rooted in implicit/impulsive system and the need to inhibit that response rooted in explicit/deliberated system. (Nieuwenhuis, Yeung, van den Wildenberg, & Ridderinkhof, 2003). Thus, in post-EP GNG task, the more negative N200 amplitude in NoGo trials with food stimuli used in E-block in EP can be explained with an increased modulation of food value with monitoring the conflict between implicit, impulsive response and explicit, deliberated control.

Our significant N200 effect was found at the electrode F7 which corresponds to left DLPFC. Previous studies using fMRI or EEG investigating self-control towards food stimuli have reported the important role of DLPFC (Carbine et al., 2018; Han et al., 2018). Furthermore, Han et al (2018) pointed out that neural activity in the left DLPFC, rather than the right, has been frequently reported in neuromodulation studies, with stimulation-induced changes in food craving and intake, indicating the important role of the left DLPFC in the link between self-control and real-world eating-related behaviors (Carbine et al., 2018; Han et al., 2018). Differently from studies in which the neural stimulation was used (Lapenta, Sierve, de Macedo, Fregni, & Boggio, 2014), the EP paradigm was applied as a manipulation to strengthen the link between food and a certain concept (i.e., healthiness). Thus, it might not be surprising that the effect was found in the left and not in the right DLPFC. The left DLPFC is known to play an important role in changing representations of information in working memory or in forming new representations by integrating the stimulus feature with other types of information (Courtney, 2004). Also, according to reflective-impulsive model, the comparably slow self-control process is based on deliberated thinking involving symbolic representations and information operations (Smith & DeCoster, 2000; Strack & Deutsch, 2004). Thus, increased N200 effect at left DLPFC in our study might be evidence of the role of left DLPFC in online value computations as well as monitoring and integrating predominant responses (e.g., impulsivity) and the inhibitory response by integrating newly-acquired stimulus-information pairing (i.e., Minimally-Processed food paired with the concept of healthiness) (Han et al., 2018).

Finally, in line with the results of the rating during EP task we didn’t find significantly increased N200 effect for Minimally-Processed High-Calorie and Heavily-Processed High-Calorie food. One possibility is that High-Calorie food has other predominantly-rooted values (i.e., positivity and hedonic value) (Houben et al., 2010; Killgore & Yurgelun-Todd, 2007; Rozin & Millman, 1987) that made it difficult to be integrated with newly-acquired stimulus-information, resulting in unchanged process of monitoring and integrating predominant responses (e.g., impulsivity) and the inhibitory response. Lastly, although larger P300 effect has been reported to be an index of response inhibition, it is probably related more to the attentional or emotional processing that influences self-control. For example, increased P300 effect has been linked to the salience of food stimuli, indicating conscious allocation of attention (Watson & Garvey, 2013). Moreover, increased P300 effect was found in response to more emotionally-charged or arousing stimuli, suggesting increased allocation of motivational or emotion-based attention. Thus, the fact that we found no P300 effect here might be due to the features of the task and experimental design which were not intended to investigate allocation of stimuli-related attention.

5. Conclusion of Study 3

The present study provided evidence at the behavioral and neural levels that self-control towards food stimuli improved through the evaluative priming, and identified the possible role of left dorsal lateral prefrontal region in the online value modulation and in integrating the stimulus feature with related information that is necessary for self-control process based on deliberated thinking with symbolic representations and information operations.

CHAPTER 5

General Discussion

The present thesis provided a basic roadmap to understand how food-related information affects cognitive and neural mechanisms underlying visual food stimuli processing and food choice. In *Chapter 1* I have reviewed the literature about the several determinants affecting our food choice including biological, physical, psychological, cognitive, social, and economic factors. Among them, I examined the relationship between food features, implicit/explicit associations towards food, and food choice, focusing on how food-related socio-psychological information (e.g., social status, healthiness, hedonic pleasure, efficiency, etc.) is implicitly and/or explicitly associated with the food and how the associations predict the food choice (*Chapter 2*). Moreover, after identifying specific associations between food and food-related information, changes of these associations were observed via the associative learning paradigm, indicated by changes of behavioral indexes and the underlying neural signatures (*Chapters 2 and 3*). Importantly, I observed that the changes of the neural signature correlated with individual characteristic related to food choice and eating habits (e.g., level of impulsivity). Based on this I was able to envisage the possibility of applying an associative paradigm and neuroimaging technique for treatment or prevention of obesity or eating disorders (*Chapter 3*). The associative learning paradigm was also proved to be effective in improving self-control toward visual food stimuli by modulating food value and monitoring the conflict between implicit/impulsive response and explicit/deliberated response (*Chapter 4*).

1. Summary of the results

In *Chapter 2*, I found that specific socio-psychological constructs (i.e., social status) are implicitly and explicitly associated with different drinks and such association guide our choice. Italian young adults possess strong implicit associations between Tea and low social-status and between Coffee and high social-status as measured by the Implicit Association Test. Moreover, these implicit associations predicted the choice of Tea/Coffee in daily-life scenarios. Furthermore, these associations can be successfully changed through an associative learning paradigm (i.e., evaluative conditioning, EC) suggesting this paradigm as a potential tool to promote changes in drink/food choices. Here in the EC paradigm, the association between food (i.e., Tea) and food-related socio-psychological information (i.e., words representing high social status) was strengthened. Indeed, after EC, Implicit and explicit associations between Tea and high social-status for Tea significantly increased as did the explicit association. Even though I found no significant changes in the number of Tea chosen at the group level, at the individual level the change in implicit associations predicted the change in choice.

In *Chapter 3*, I focused on food choice including minimally-processed and heavily-processed food. I thus investigated the neural mechanisms underlying the change in associations between food (i.e., minimally-processed and heavily-processed food) and specific food-related semantic information (i.e., healthiness and sustainability) through an EC-based task. I exploited the N400, known to detect incongruency, to track the conflict between a prime (information related to health and sustainability) and a target (different foods). Behaviorally, EC-based intervention successfully strengthened the implicit and explicit associations between minimally-processed food and the concept of healthiness/sustainability. More importantly, the prime-target pairs including the concept of unhealthiness/unsustainability and Minimally-Processed food elicited greater N400 effect in left DLPFC. In addition, the positive correlation between the N400 effect in left DLPFC and individuals' level of impulsivity (i.e., attentional and non-planning impulsiveness) was significant. The results suggest that the DLPFC plays a role in changing or forming representations by integrating the stimulus feature with other types of information, and in improving impulsivity toward food.

In *Chapter 4*, I investigated whether the self-control of response toward unhealthy food can be improved. The evaluative priming (EP), that is a variation of the EC procedure, was used to strengthen the association between a prime (i.e., health information) and a target (i.e., minimally-processed food as target). In this paradigm, participants rate their liking of the target immediately. Participants performed a Go/NoGo task with EEG before (pre-EP) and after (post-EP) EP. Two inhibition-related neural signatures were targeted: the P300 waveform that is elicited when food stimuli are presented, and the N200 that is elicited when self-control is required. During the EP, I observed higher subjective liking of Minimally-Processed Low-Calorie food images when they were systematically paired with a concept (in evaluative block). The results for the GNG tasks show a significant interaction between time point (pre- and post-EP), category of stimuli (evaluative-block food images, control-block food images, and artificial object), and electrode (F3, F5, F7, F4, F6, F8) for the N200 effect. Averaged amplitude at electrode F7 for food images systematically paired to a concept in EP was more negative in post-EP than in pre-EP GNG. According to the further inspection, and considering also the degree of process and calorie, more negative N200 amplitudes were consistently found at electrode F7 (left DLPFC, BA47/46) in post-EP GNG task for Heavily-Processed Low-Calorie food as well as for Minimally-Processed Low-Calorie food, but not for Heavily-Processed High-Calorie food and Minimally-Processed High-Calorie food. In this study no P300 effect of interest was found.

2. Theoretical implications and practical applications

There are biological, physical, psychological, cognitive, social (i.e., culture, family, and peers), and economic determinants that can affect our food choice. According to our findings, a particular attention deserves the food-related semantic information input and its associations (implicit/explicit) with food. This input clearly influences the processing of food stimuli or food choice. Thus, food-related semantic information playas the role as external inputs which influences the interaction between existing and newly-acquired implicit/impulsive and explicit/reflective associations, resulting in the changes of processing of food stimuli or choice.

Indeed, many health-related problems, including unhealthy dieting patterns or unhealthy food choices, can be framed as a conflict between immediate, implicit impulsive responses and reflective, explicit decision-making processes (e.g., restrained behavior) (Carver, 2005; Hofmann et al., 2008). The theoretical framework of reflective-impulsive model, proposed by Strack and Deutsch (2004), try to explain different social behaviors, including food consumption (see Figure 4 in Strack & Deutsch, 2004) as a joint function of reflective and impulsive processes, follow different operating principles of information processing. The reflective process produces behavioral decisions based on knowledge and values, while the impulsive process generates automatic behavioral responses through associative links and motivational orientations (Strack & Deutsch, 2004). Importantly, the reflective system depends on symbolic representations and information operations, structured by language and logic. These symbolically represented rules can be learned from one or a more experiences, with the presence of conscious awareness. In contrast, the impulsive system depends on associations based on similarity and contiguity which are learned over many experiences and might occur without awareness (Smith & DeCoster, 2000; Strack & Deutsch, 2004).

I argued that the drive of unhealthy food choice is rooted in the unbalanced interaction between implicit/impulsive and explicit/reflective systems that could be improved by strengthening or weakening the associations between food and food-related information through the associative learning paradigm (i.e., evaluative conditioning). Although I failed to find direct and immediate changes in food choice after the application of the associative learning paradigm, our results did fit the theoretical framework of reflective-impulsive model (Strack & Deutsch, 2004). In *Chapter 2 and 3*, I found consistent changes of both implicit and explicit associations between certain food (i.e., Minimally-Processed food) and related information (i.e., concept of healthiness) only for food images being conditioned. In *Chapter 4*, I further confirm that strengthening the associations between Minimally-Processed/Heavily-Processed food and the concept of healthiness/unhealthiness could reduce impulsivity towards food only for food images in the evaluative block, that is, food images which were conditioned. In *Chapters 3 and 4*, I also concluded that left DLPFC might play a critical role in changing representations of information in working memory or in forming new representations by integrating the stimulus feature with other types of information (Courtney, 2004), indexed by larger N400 effects which indicated greater semantic conflict between incongruent food-concept pairs. Especially, participants who possessed stronger impulsive traits showed greater changes of N400 effects, indicating the potential value of the paradigm as an effective intervention for individuals with impulsive eating habits. By integrating newly-acquired stimulus-information pairing (i.e., Minimally-Processed food paired with the concept of healthiness), increased N200 effect implied also the role of left DLPFC in modulating food value and monitoring and integrating predominant responses (e.g., impulsivity) and deliberated response (e.g., self-control).

The main results of the present thesis suggested that associative learning paradigm could be a potential intervention used for changing food choice and adjusting unhealthy eating behavior. Individuals with more impulsive eating habits (i.e., obesity) or individuals with conflicting interaction between impulsive and controlled eating habits (i.e., restrained eaters) could benefit most from this intervention.

3. Limitations and future directions

My thesis has several limitations. First, the number of participants in my studies is not always ideal because it hampers the statistical power. Second, I failed to pay sufficient attention to the investigation and comparison of different features and parameters and the potential for larger-scale applicability. In order to maximize the effect of an intervention, the experimental procedure and features should be further investigated by addressing also the influence of characteristic of associative learning paradigm (i.e., duration of exposure to the intervention, resistance to extinction, influence of participants' contingency awareness of CS-US pairing, context settings, etc.) on its effect (De Houwer, 2001; Hofmann et al., 2010).

Moreover, to increase the ecological validity and the effect of the intervention, proper stimuli (i.e., unconditioned stimuli and conditioned stimuli in EC or primes and targets in EP) should be selected for individuals with different characteristics or eating habits (e.g., people with obesity, restrained eaters, people with anorexia, etc.). For example, the contrasted food categories can be natural food versus transformed food, minimally-processed versus heavily-processed food, high-calorie versus low-calorie food, sweet food versus salty food, meat versus vegetable. However, if participants already possessed predominant associations between food and related-information (i.e., natural food is healthy), the effect might be limited (i.e., more difficult to strengthen an already strong associations between natural food and the concept of healthiness). Thus, the purpose of the intervention and the selection of stimuli should be carefully considered.

The third limitation is that the detailed processing underlying the interaction between explicit/reflective and implicit/impulsive systems needs to be further examined. For example, Gawronski and Bodenhausen (2006) proposed the associative–propositional evaluation (APE) model with specific assumptions about the mutual interplay of the two processes, discussing possible mechanisms underlying symmetric or asymmetric changes in implicit and explicit processes (Gawronski & Bodenhausen, 2006). Linked to my results in *Chapter 1*, the corresponding changes between explicit and implicit associations might imply that strengthened link between Tea and high social status directly influenced both associative evaluations (implicit level) and propositional reasoning (explicit level) with mutual indirect influences between the two levels, as described by Gawronsli & Bodenhausen (2006), *Case 8* (Gawronski & Bodenhausen, 2006). However, more detailed experimental designs and statistical analyses are needed in order to further investigate the relation between the change within each system and the behavioral output (i.e., food choice).

Finally, it will be especially necessary but also challenging to explore the change of the neural mechanisms underlying the interaction of the implicit/impulsive and explicit/deliberated systems before and after the associative learning paradigm being applied, and its relation to the change of choice. The localization of the ERP effects (i.e., N400 and N200) could be further explored using source analyses and by using the fMRI.

Table 2.1 Descriptive statistics relative to the selected set of picture stimuli.

	Picture Category		
Association to:	**Coffee** *M (SD)*	**Tea** *M (SD)*	**t-test**
Coffee	88.72 (11.03)	9.61 (6.39)	$t(26)= 23.23$, $p=.00$*
Tea	12.42 (12.85)	90.07 (6.62)	$t(26)= -20.09$, $p=.00$*
Social status	44.04 (9.46)	48.76 (7.27)	$t(26)= -1.48$, $p=.15$
Hedonic Pleasure	50.65 (14.37)	47.11 (15.97)	$t(26)= .62$, $p=.54$
Healthiness	45.68 (8.97)	46.98 (15.98)	$t(26)= -.27$, $p=.79$
Efficiency	53.41 (7.03)	51.49 (6.51)	$t(26)= .75$, $p=.46$
Valence	60.23 (11.32)	64.00 (10.44)	$t(26)= -.92$, $p=.37$
Arousal	45.73 (14.95)	41.00 (17.69)	$t(26)= .76$, $p=.45$

NOTES. Original stimuli were: 30 Coffee pictures and 30 Tea pictures. *M (SD):* Mean (Standard deviation). *$P < .05$.

Table 2.2 **S**tatistics of selecting the final sets of word stimuli for implicit and explicit measurements as well as for EC task.

		Word Category							
Association to:		**High Social status**	**Low Social status**	**Hedonic pleasure/ unpleasant**	**Healthiness/ unhealthiness**	**Efficiency**	**Inefficiency**	**Positivity**	**Negativity**
Coffee	*M*	21.74	16.51	29.22	35.46	29.69	19.86	23.00	20.00
	(*SD*)	(9.37)	(11.82)	(13.35)	(17.92)	(7.49)	(12.35)	(17.69)	(19.84)
	t-test	$t(12)= .92, p=.38$		$t(12)= -.74, p=.47$		$t(12)= 1.80, p=.10$		$t(12)= .45, p=.66$	
Tea	*M*	14.29	12.63	40.57	27.13	21.98	15.54	27.25	10.81
	(SD)	(6.18)	(8.71)	(25.73)	(13.13)	(3.99)	(11.82)	(20.03)	(6.67)
	t-test	$t(12)= .41, p=.69$		$t(12)= 1.23, p=.25$		$t(12)= 1.37, p=.20$		$t(12)= 2.31, p=.054$	
Social status	*M*	77.09	55.43	51.95	45.79	52.34	44.34	41.14	42.32
	(SD)	(11.64)	(12.58)	(16.30)	(9.36)	(8.00)	(10.67)	(20.68)	(19.51)
	t-test	$t(12)= 3.34, p=.006$*		$t(12)= .87, p=.40$		$t(12)= 1.59, p=.14$		$t(12)= -.03, p=.96$	
Hedonic pleasure	*M*	30.11	31.38	50.07	31.53	35.14	26.13	59.58	18.28
	(SD)	(9.38)	(8.31)	(26.90)	(17.43)	(10.01)	(19.12)	(16.74)	(5.09)
	t-test	$t(12)= -.27, p=.79$		$t(12)= 2.27, p=.04$*		$t(12)= 1.10, p=.30$		$t(12)= 6.30, p=.000$*	
Healthiness	*M*	29.96	38.92	47.97	63.32	30.79	31.59	34.11	59.28
	(SD)	(25.31)	(24.63)	(9.73)	(12.29)	(4.40)	(10.18)	(19.17)	(19.89)
	t-test	$t(12)= -.67, p=.52$		$t(12)= -2.59, p=.02$*		$t(12)= -.19, p=.85$		$t(12)= -1.82, p=.09$	
Efficiency	*M*	56.96	55.11	49.68	38.24	84.20	25.50	53.82	26.89
	(SD)	(13.35)	(9.78)	(19.15)	(16.63)	(6.59)	(2.58)	(15.10)	(7.69)
	t-test	$t(12)= .30, p=.77$		$t(12)= 1.19, p=.26$		$t(12)= 21.93, p=.000$*		$t(12)= 3.69, p=.004$*	
Valence	*M*	53.20	56.33	64.63	36.93	79.52	24.09	82.66	15.73
	(SD)	(5.55)	(11.31)	(32.13)	(25.39)	(4.17)	(8.43)	(7.37)	(15.73)
	t-test	$t(12)= -.66, p=.52$		$t(12)= 1.79, p=.10$		$t(12)= 15.60, p=.000$*		$t(12)= 17.34, p=.000$*	
Arousal	*M*	26.26	31.61	56.73	47.50	53.53	35.20	64.34	51.52
	(SD)	(8.05)	(4.26)	(13.78)	(15.85)	(5.12)	(11.04)	(18.46)	(6.24)

	t-test	*t*(12)= -1.55, *p*=.15		*t*(12)= 1.16, *p*=.27		*t*(12)= 3.99, *p*=.002*		*t*(12)= 1.94, *p*=.08	
Number of letter	*M*	7.14	8.14	9.86	9.13	10.00	11.00	6.29	5.83
	(SD)	(1.68)	(2.04)	(3.58)	(2.91)	(1.73)	(2.08)	(0.95)	(0.75)
	t-test	*t*(12)= 1.00, *p*=.34		*t*(12)= .41, *p*=.69		*t*(12)= -.98, *p*=.35		*t*(12)= .00, *p*=1.00	
Word frequency	*M*	74.86	38.71	16.71	119.14	153.43	10.43	248.14	415.67
	(SD)	(107.25)	(36.87)	(18.97)	(222.76)	(179.77)	(18.50)	(164.71)	(414.06)
	t-test	*t*(12)= .84, *p*=.42		*t*(12)= -1.21, *p*=.25		*t*(12)= 2.10, *p*=.08		*t*(12)= -.71, *p*=.49	

NOTES. Original number of stimuli and examples of stimuli in English translations with original Italian word within parentheses: 20 for low social status (e.g. HOSTEL (OSTELLO) and 20 for high social status words (e.g., DOCTOR (DOTTORE)); 13 for hedonic pleasure (e.g. SATISFACTION (SODDISFACIMENTO)) and 13 for unpleasantness words (e.g. DISCOMFORT (SCOMODITÀ); 11 for healthiness (e.g., STRENGTH (FORZA)) and 11 for unhealthiness words (e.g. AGITATION (AGITAZIONE)); 13 for efficiency (e.g., PRECISION (PRECISIONE)) and 13 for inefficiency words (INABILITY (INCAPACITY)); 15 for negativity (e.g., DEATH (MORTE)) and 15 for positivity words (VICTORY (VITTORI)). *M* (*SD*): Mean (Standard deviation). t-test: Independent-sample t-test. *$p < .05$.

Table 3.1 Mean, Standard deviation and Statistics for the image stimuli for Heavily-processed food, Minimally-processed food, high-calorie food, and Low-calorie food on the piloted dimensions.

		Image Category			
		Heavily-processed	Minimally-processed	High-calorie	Low-calorie
Degree of process	M (SD)	68.47 (5.80)	46.03 (10.94)	57.79 (12.78)	56.70 (15.74)
	t-test	t(78)= 11.47, p=.000*		t(78)= .34, p=.734	
Calorie content per 100g	M (SD)	329.75 (162.69)	300.18 (181.85)	444.08 (132.37)	185.85 (90.94)
	t-test	t(78)= .767, p=.446		t(78)= 10.17, p=.000*	
Perceived Calorie content	M (SD)	72.69 (11.49)	53.40 (13.71)	65.30 (15.26)	60.78 (16.35)
	t-test	t(78)= 6.82, p=.000*		t(78)= 1.28, p=.205	
Immediate edibility	M (SD)	34.81 (5.72)	34.04 (7.98)	32.72 (12.78)	36.13 (6.09)
	t-test	t(78)= .50, p=.621		t(78)= -.2.26, p=.027*	
Valence	M (SD)	44.32 (9.86)	53.83 (10.92)	47.59 (10.88)	50.56 (11.83)
	t-test	t(78)= -4.09, p=.000*		t(78)= -1.17, p=.246	
Familiarity	M (SD)	40.82 (13.22)	46.14 (15.92)	44.00 (15.18)	42.96 (14.55)
	t-test	t(78)= -1.63, p=.108		t(78)= .31, p=.756	
Typicality	M (SD)	61.41 (11.26)	60.69 (12.64)	61.22 (12.56)	60.87 (11.37)
	t-test	t(78)= .27, p=.789		t(78)= .13, p=.895	

Discriminability	M (SD)	16.67 (12.93)	21.78 (18.97)	21.31 (19.20)	17.15 (12.77)
	t-test	t(78)= -1.41, p=.164		t(78)= 1.14, p=.256	
Arousal	M (SD)	48.11 (16.36)	42.34 (13.46)	43.28 (14.27)	47.16 (15.96)
	t-test	t(78)= 1.72, p=.089		t(78)= -1.15, p=.255	
Spatial frequency of image	M (SD)	.005 (.003)	.005 (0.003)	.004 (.003)	.005 (.003)
	t-test	t(78)= .19, p=.849		t(78)= -1.50, p=.138	
Brightness of image	M (SD)	203.43 (25.02)	209.43 (19.71)	207.89 (23.69)	204.97 (21.62)
	t-test	t(78)= -1.19, p=.237		t(78)= .57, p=.568	
Size of image	M (SD)	.56 (.18)	.55 (.17)	.574 (.183)	.533 (.165)
	t-test	t(78)= 4.13, p=.681		t(78)= 1.07, p=.286	

NOTES. Number of stimuli: 20 for Heavily-processed High-calorie food, 20 for Heavily-processed Low-calorie food, 20 for Minimally-processed High-calorie food, and 20 for Minimally-processed Low-calorie food. Mean (Standard deviation): *M* (*SD)*, Independent-sample t-test: t-test. *p < .05.

Table 3.2 Mean, Standard deviation and Statistics for the word stimulus material for Healthiness-words, Unhealthiness-words, sustainable-words, and unsustainable-words on the piloted dimensions.

		Word Category			
		Healthiness	**Unhealthiness**	**Sustainability**	**Unsustainability**
Related to healthiness	*M* (*SD*)	83.46 (10.43)	14.00 (8.59)	73.34 (16.06)	24.41 (17.44)
	t-test	*t*(18)= 16.26, *p*=.000*		*t*(18)= 6.53, *p*=.000*	
Related to sustainability	*M (SD)*	77.47 (6.27)	17.98 (8.10)	72.54 (14.03)	27.17 (17.19)
	t-test	*t*(18)= -18.34, *p*=.000*		*t*(18)= 6.47, *p*=.000*	
Valence	*M (SD)*	83.14 (5.75)	14.20 (9.58)	71.01 (20.54)	26.64 (17.47)
	t-test	*t*(18)= 19.51, *p*=.000*		*t*(18)= 5.20, *p*=.000*	
Arousal	*M (SD)*	58.13 (5.98)	54.76 (5.89)	56.54 (7.81)	52.63 (6.78)
	t-test	*t*(18)= 1.27, *p*=.220		*t*(18)= 1.20, *p*=.248	

NOTES. Number of stimuli and examples of stimuli presented here in their English translations with original Italian word within parentheses: 10 for healthiness e.g., NUTRITION (NUTRIZIONE); 10 for unhealthiness e.g., MALNUTRITION (MALNUTRIZIONE); 10 for sustainability e.g., SUSTAINABILITY (SOSTENIBILITÀ); and 10 for unsustainability e.g., UNSUSTAINABILITY (INSOSTENIBILITÀ). Mean (Standard deviation): *M* (*SD),* Independent-sample t-test: t-test. *$p < .05$.

Table 3.3 Mean and standard deviation (SD) of the behavioral results for each category of food stimuli in Semantic congruency (SC) task, explicit ratings, and behavioral choice task (number of purchased products).

		EC-based condition				**Control condition**			
Task		**HH**	**HL**	**MH**	**ML**	**HH**	**HL**	**MH**	**ML**
SC-accuracy	Mean	0.74	0.70	0.79	0.83	0.81	0.69	0.75	0.77
	SD	0.14	0.14	0.13	0.13	0.10	0.11	0.11	0.12
SC-RT(ms)	Mean	478.89	463.26	487.05	481.26	388.49	382.09	380.32	390.14
	SD	126.75	141.43	129.99	120.13	113.3	107.18	106.38	103.35
Rating-Healthiness	Mean	29.22	35.86	64.71	73.99	28.74	31.80	61.67	63.59
	SD	10.67	9.59	10.85	10.45	9.68	9.22	8.21	10.52
Rating-Sustainability	Mean	34.20	36.54	69.05	74.02	32.80	35.46	69.12	68.76
	SD	14.50	13.49	10.41	11.46	16.31	16.41	11.08	10.30
Rating-Preference	Mean	58.51	55.67	62.97	61.73	44.53	56.21	58.63	66.34
	SD	14.08	13.94	10.31	15.08	15.82	16.08	12.32	8.36
Number of purchased product	Mean	3.11	3.83	5.17	23.67	2.83	4.56	5.06	24.11
	SD	3.66	2.98	3.84	9.44	2.20	3.18	4.22	8.69

NOTE. HH: Heavily-processed high-calorie food, HL: Heavily-processed low-calorie food, MH: Minimally-processed low-calorie food, ML: Minimally-processed low-calorie food. SC: Semantic congruency task

Table 3.4 Mean and standard deviation (SD) of the IAT scores (Chohen's *d'*) for high- and low-calorie food stimuli

		EC-based condition		**Control condition**	
		HC	**LC**	**HC**	**LC**
IAT-Healthiness	Mean	0.80	0.74	0.60	0.45
	SD	0.35	0.45	0.38	0.40
IAT-Sustainability	Mean	0.58	0.65	0.64	0.51
	SD	0.37	0.48	0.43	0.43

NOTE. HC: High-calorie food, LC: Low-calorie food.

Table 4.1 Mean and standard deviation and relative statistics of selected image stimuli for Evaluative Priming task as well as for Go/NoGo task.

		Image Category					
		Heavily-processed	**Minimally-processed**	**High-calorie**	**Low-calorie**	**All Food**	**Artificial Object**
Degree of process	*M*	74.04	50.36	58.74	56.27	NA	NA
	(SD)	(12.52)	(14.20)	(13.33)	(18.17)		
	t-test	t(62)= 11.74, p=.000*		t(62)= .62, p=539		NA	
Calorie content per 100g	*M*	322.69	300.28	449.19	173.78	NA	NA
	(SD)	(152.68)	(195.30)	(123.14)	(86.04)		
	t-test	t(62)= .511, p=.611		t(62)= 10.37, p=.000*		NA	
Perceived Calorie content	*M*	74.04	50.36	64.99	59.4	NA	NA
	(SD)	(12.52)	(14.20)	(15.78)	(19.56)		
	t-test	t(62)= 7.08, p=.000*		t(62)= 1.26, p=.213		NA	
Immediate edibility	*M*	33.98	33.43	32.17	35.25	NA	NA
	(SD)	(5.41)	(9.02)	(6.93)	(7.61)		
	t-test	t(62)= .29, p=.770		t(62)= -.1.69, p=.095		NA	
Valence	*M*	41.58	55.21	43.38	41.12	48.35	53.10
	(SD)	(9.64)	(10.54)	(11.10)	(13.10)	(12.20)	(6.25)
	t-test	t(62)= -5.40, p=.000*		t(62)= -1.03, p=.307		t(130)= -2.79, p=.006*	
Familiarity	*M*	38.78	45.71	44.00	41.12	42.05	38.67
	(SD)	(14.45)	(14.95)	(14.22)	(15.88)	(15.06)	(20.23)
	t-test	t(62)= -1.88, p=.064		t(62)= .60, p=.551		t(130)= 1.08, p=.280	
Typicality	*M*	59.16	61.72	61.14	59.74	60.15	62.35
	(SD)	(12.01)	(12.11)	(11.76)	(12.54)	(12.24)	(14.34)
	t-test	t(62)= -.84, p=.402		t(62)= .46, p=.648		t(130)= -.94, p=.348	

Discriminability	*M*	15.18	20.48	18.34	17.32	17.73	50.21
	(SD)	(12.01)	(16.95)	(16.55)	(13.10)	(14.89)	(284.44)
	t-test	t(62)= -1.45, p=.154		t(62)= 28, p=.784		t(130)= -.91, p=.363	
Arousal	*M*	46.07	41.33	42.42	44.98	43.43	21.93
	(SD)	(16.25)	(12.76)	(12.54)	(16.67)	(14.95)	(8.71)
	t-test	t(62)= 1.30, p=.199		t(62)= -.69, p=.490		t(130)= 10.02, p=.000*	
Spatial frequency	*M*	.004	.005	.004	.005	.004	.004
	(SD)	(.002)	(0.003)	(.002)	(.003)	(.003)	(.003)
	t-test	t(62)= -.25, p=.806		t(62)= -1.64, p=.106		t(130)= 1.73, p=.086	
Brightness	*M*	207.11	210.99	212.03	206.07	208.77	207.40
	(SD)	(21.82)	(21.04)	(18.96)	(23.53)	(21.24)	(28.36)
	t-test	t(62= -.72, p=.473		t(62)= 1.12, p=.269		t(130)= .31, p=.755	
Size	*M (SD)*	.53 (.20)	.59 (.16)	.58 (.19)	.54 (.17)	.56 (.18)	.55 (.27)
	t-test	t(62)= -1.22, p=.225		t(62)= .98, p=.331		t(130)= .30, p=.762	

NOTES. *M* (*SD*): Mean (Standard deviation). t-test: Independent-sample t-test. *$p < .05$. NA: non-applicable.

Table 4.2 Mean and standard deviation (SD) with relative statistics for selected word stimuli for Evaluative Priming task.

		Word Category	
		Healthiness	**Unhealthiness**
Related to healthiness	*M (SD)*	82.77 (6.46)	15.17 (10.46)
	t-test	*t*(14)= 13.18, *p*=.000*	
Valence	*M (SD)*	82.46 (11.11)	14.33(9.50)
	t-test	*t*(14)= 15.56, *p*=.000*	
Arousal	*M (SD)*	57.96 (6.77)	54.85 (6.67)
	t-test	*t*(14)= .93, *p*=.371	

NOTES. Number of stimuli and examples of stimuli presented here in the English translations with original Italian word within parentheses: 8 for healthiness (e.g. NUTRITION (NUTRIZIONE) and 8 for unhealthiness (e.g., MALNUTRITION (MALNUTRIZIONE)). *M* (*SD):* Mean (Standard deviation). t-test: Independent-sample t-test. **p* < .05.

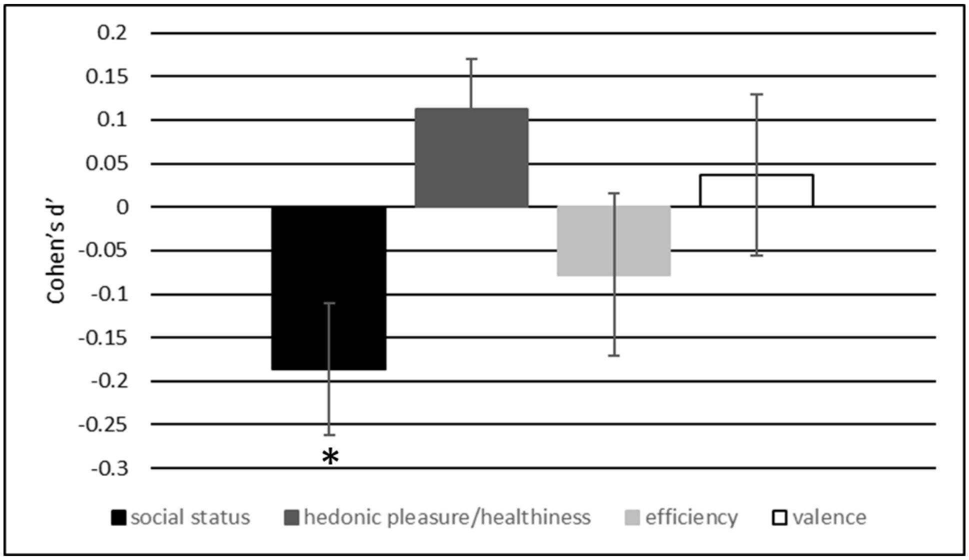
Table 4.3 Mean (SD) of accuracy, the hits rates, and false alarms rates of Go and NoGo trials for each category of food images used in each type of blocks in EP in pre- and post-EP GNG tasks.

		Pre-EP GNG task			
Images		**RT (ms)**	**Accuracy**	**Hits rates**	**False alarms rates**
Food (E-block)	Go trials	82.77 (6.46)	.98 (.02)	98 (.02)	NA
	NoGo trials	NA	.95 (.03)	NA	.05 (.03)
Food (control-block)	Go trials	503.14 (83.04)	.99 (.02)	.99 (.02)	NA
	NoGo trials	NA	.95 (.04)	NA	.05 (.04)
Artificial objects	Go trials	496.11 (66.48)	.98 (.02)	.98 (.02)	NA
	NoGo trials	NA	.97 (.04)	NA	.03 (.04)
		Post-EP GNG task			
Food (E-block)	Go trials	472.64 (64.19)	.98 (.04)	.98 (.04)	NA
	NoGo trials	NA	.94 (.06)	NA	.06 (.06)
Food (control-block)	Go trials	467.84 (64.19)	.99 (.01)	.99 (.01)	NA
	NoGo trials	NA	.93 (.09)	NA	.07 (.09)
Artificial objects	Go trials	482.71 (55.37)	.98 (.02)	.98 (.02)	NA
	NoGo trials	NA	.95 (.03)	NA	.05 (.03)

NOTES. Food (E-block): food images used in the E-block of Evaluative Priming task. Food (control-block): food images used in the control block of Evaluative Priming task The Hits rates is calculated as the ratio between the number of correct Go responses and the total number of Go-trials in a given block; false alarms rates are calculated as the ratio between the numbers of incorrect responses and the total number of NoGo trials. NA: non-applicable.

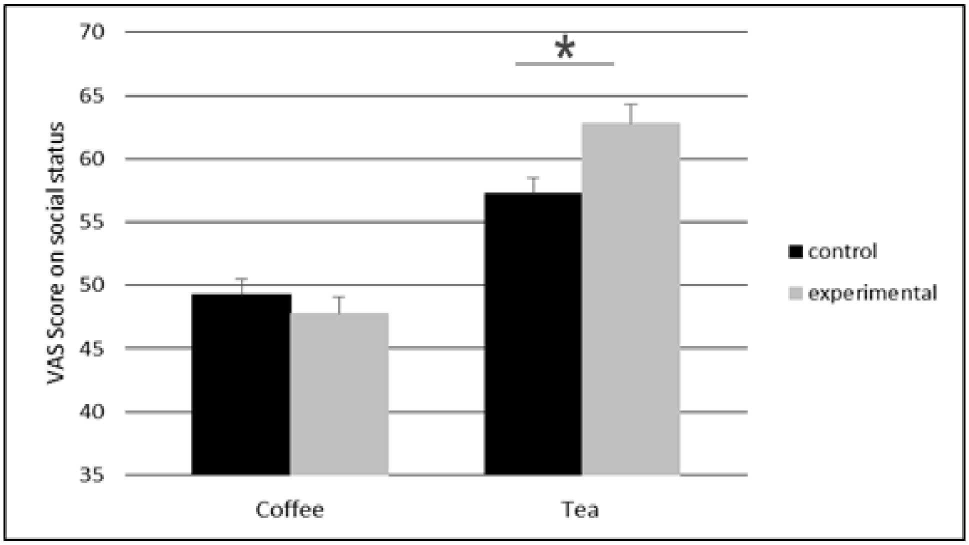
Figure 2.1 Example of Coffee (upper row) and Tea (lower row) picture **s**timuli selected for the experiments. Original pictures were presented in color.

Figure 2.2 Results of one-sample t-tests: IAT scores (Cohen's *d')* for each construct of interest. Positive values indicate that Tea is associated with high social status, hedonic pleasure, efficiency, and positivity. Negative values indicate that Tea is associated with low social status, healthiness, inefficiency, and negativity.



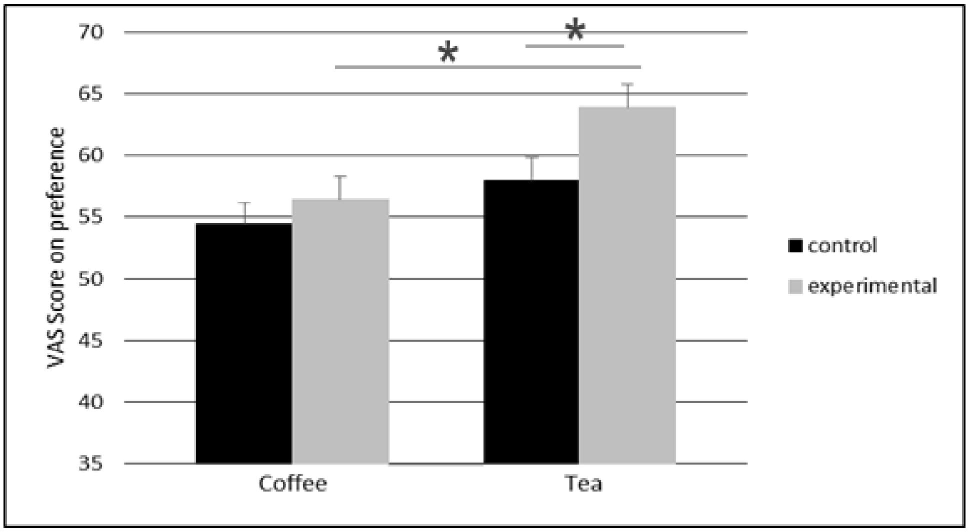
NOTE. *p < .05.

Figure 2.3 Explicit association between Coffee and Tea and social status across conditions (control vs. experimental). Higher scores indicate association between a given drink and high social status.



NOTE. *$p < .05$.

Figure 2.4 Participants' explicit association with preference for Coffee and Tea across conditions (control vs. experimental). Higher scores indicate more preference for the target drink.



NOTE. *$p < .05$.

Figure 3.1 Example of imaged of Minimally-processed Low-calorie food (i.e., canned fruit) Minimally-processed High-calorie food (i.e., dried fruit bread), Heavily-processed Low-calorie food (i.e.,sugary dried fruit), and Heavily-processed High-calorie food (i.e., fried apple pie) selected for the EC task, SC task, IATs, and explicit ratings. Original images were presented in color.

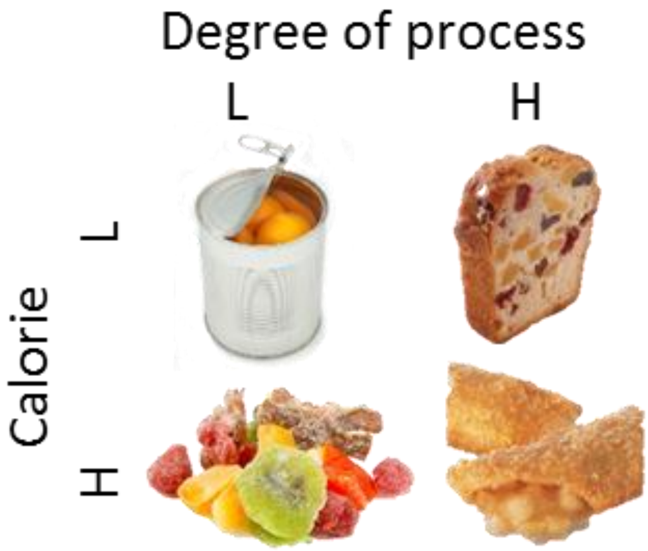


Figure 3.2 Trial structure for the semantic congruency task representing an example of incongruent trial.

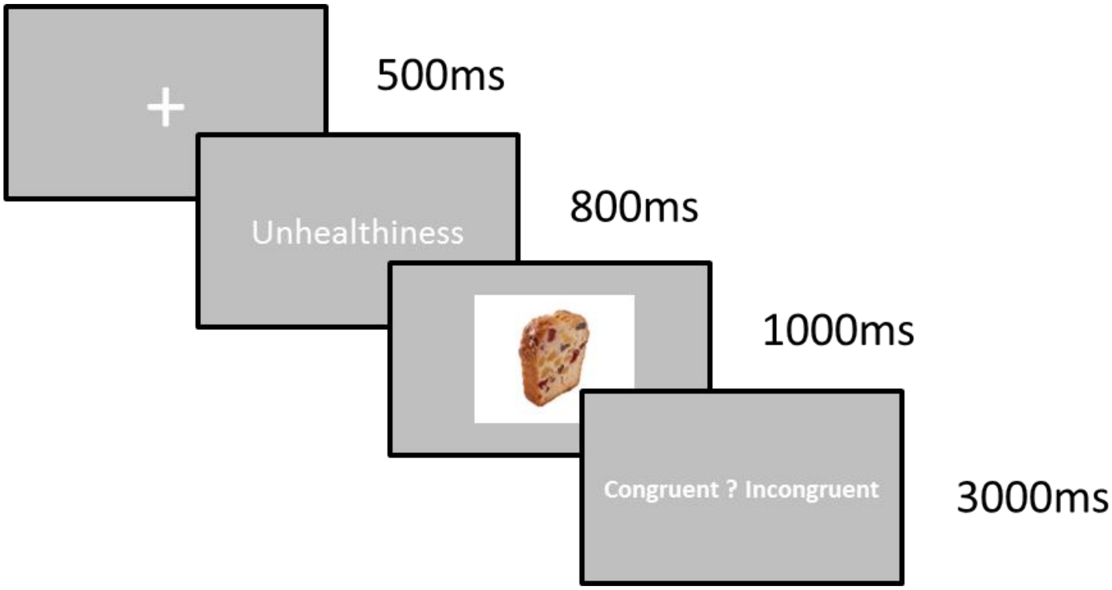


Figure 3.3 Accuracy in incongruent trials of the semantic congruence task for HP-food/high-calorie, for HP-food/low-calorie, for MP-food/high-calorie, and HP-food/low-calorie in control and EC-based condition. Significant interaction between condition and degree of process was marked by an *. Error bars indicate the standard error of the means.

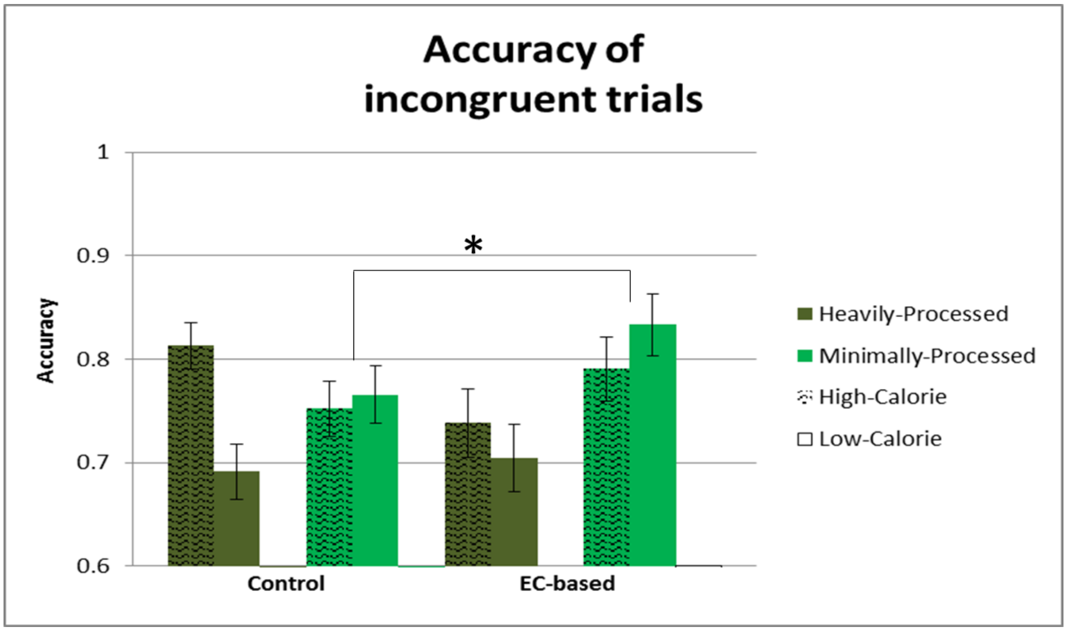


Figure 3.4 Explicit rating of healthiness for HP-food/high-calorie, for HP-food/low-calorie, for MP-food/high-calorie, and HP-food/low-calorie in control and EC-based condition. Significant interaction between condition and degree of process was marked by an *. Error bars indicate the standard error of the means.

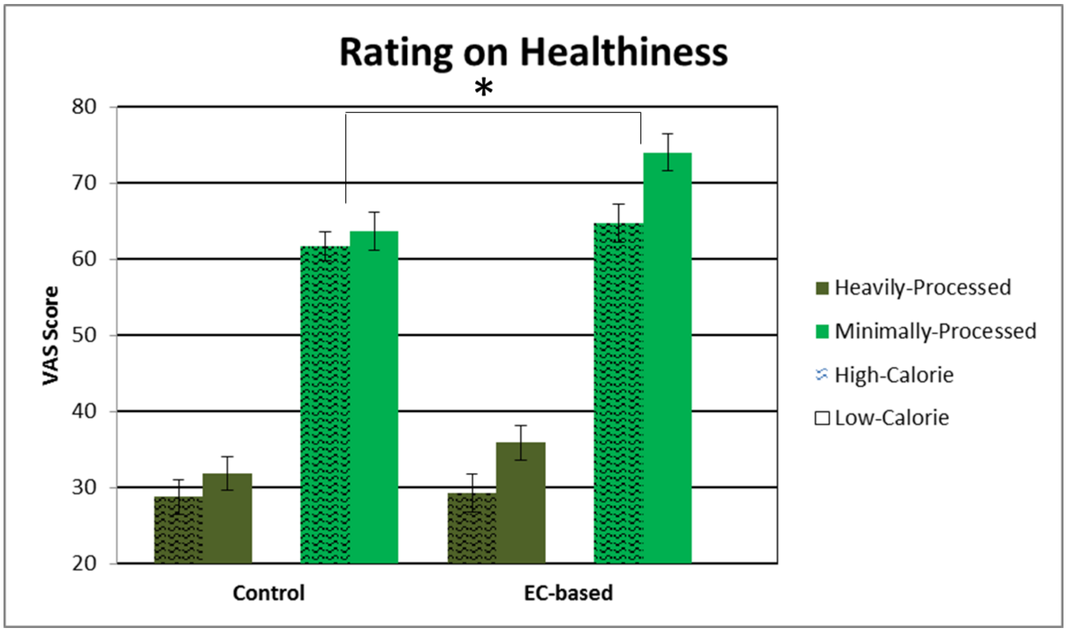


Figure 3.5 Number of products purchased in the virtual supermarket task for HP-food/high-calorie, for HP-food/low-calorie, for MP-food/high-calorie, and HP-food/low-calorie in control and EC-based condition. There was a significant interaction between degree of process and calorie. Participants chose more Minimally-Processed food than Heavily-Processed food within the range of Low-Calorie food, marked by an *. Error bars indicate the standard error of the means.

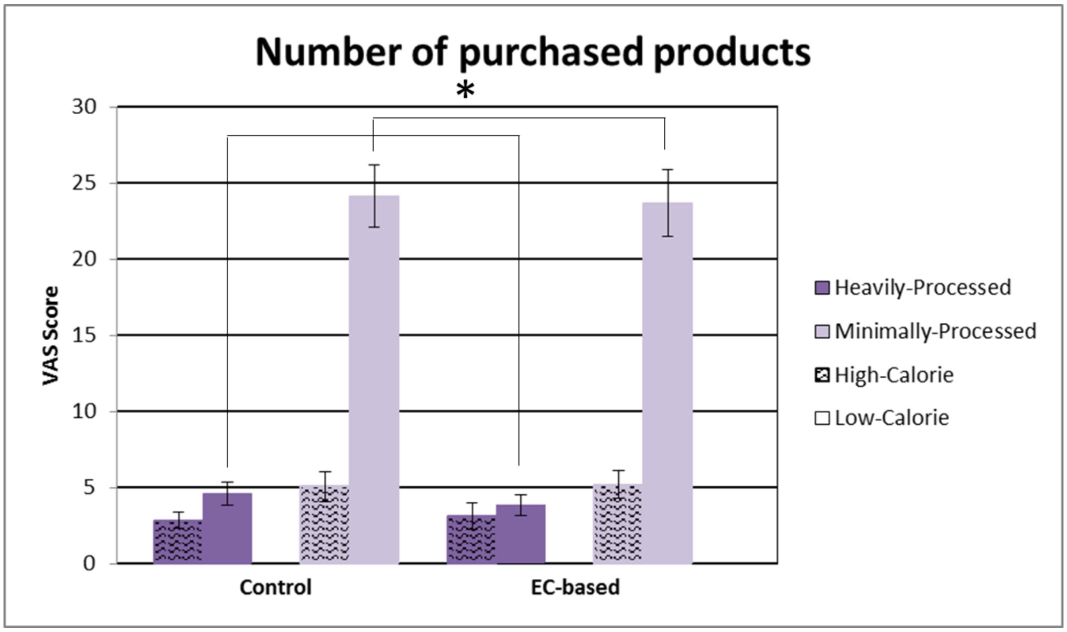
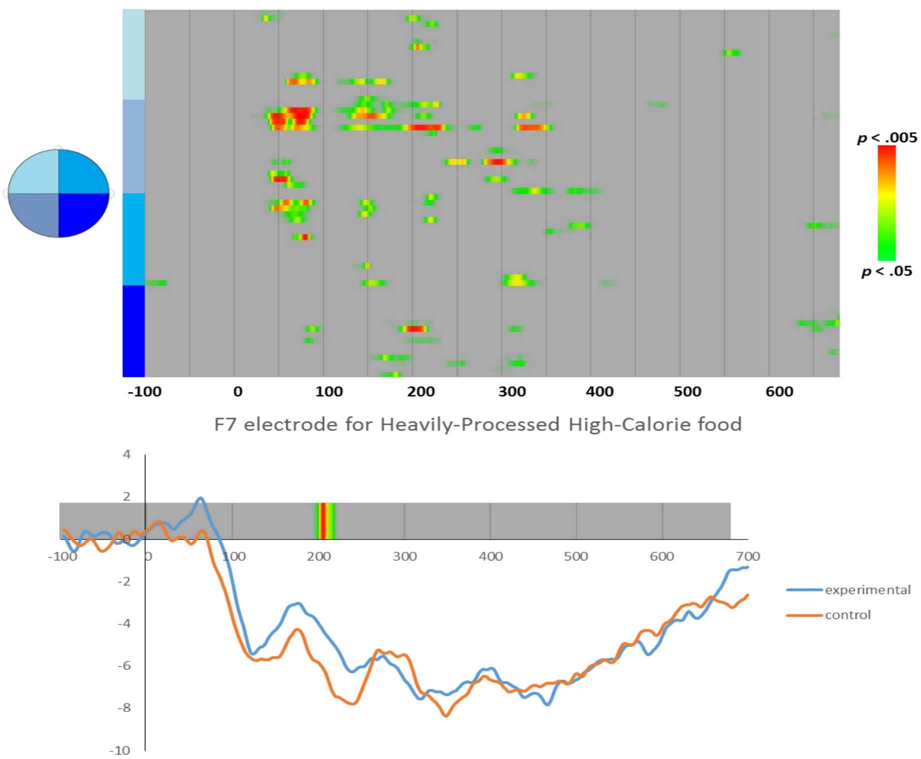
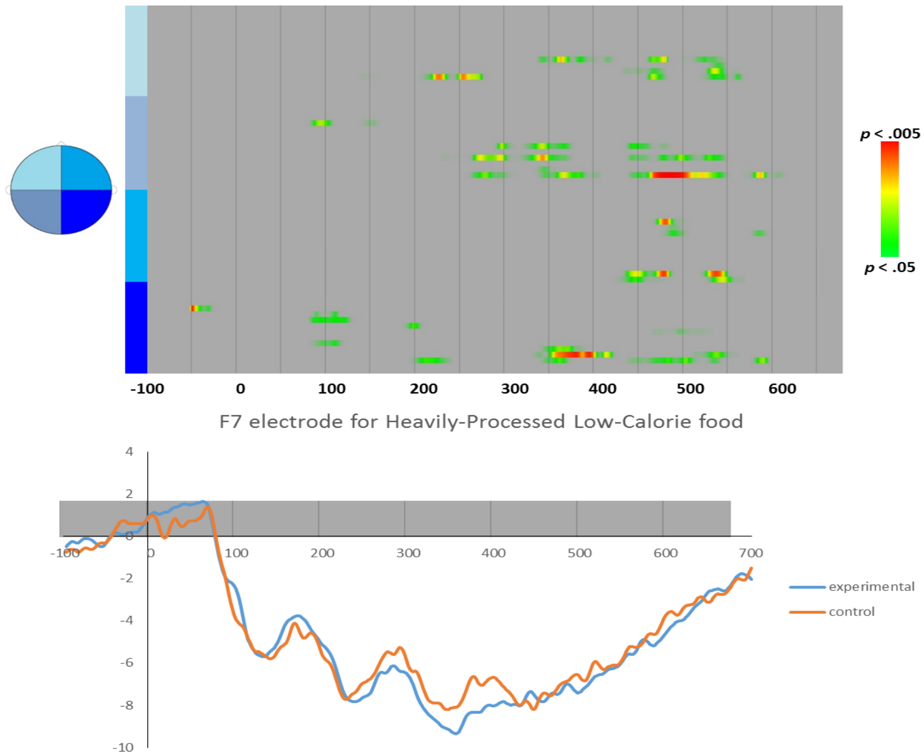


Figure 3.6 Averaged brain waveform for each category of food at electrode F7. In each sub-figure, the upper part indicate the significant *p*-values of the paired t-test between experimental and control conditions in the whole brain and the lower part indicate the averaged brain waveform for each category of food at electrode F7 for (a) Heavily-Processed High-Calorie food, (b) Heavily-Processed Low-Calorie food, (c) Minimally-Processed High-Calorie food, and (d) Minimally-Processed High-Calorie food. Most importantly, the averaged amplitude at electrode F7 for Minimally-Processed food was significantly different between conditions, with more negative averaged amplitudes were found in experimental condition.

(a)

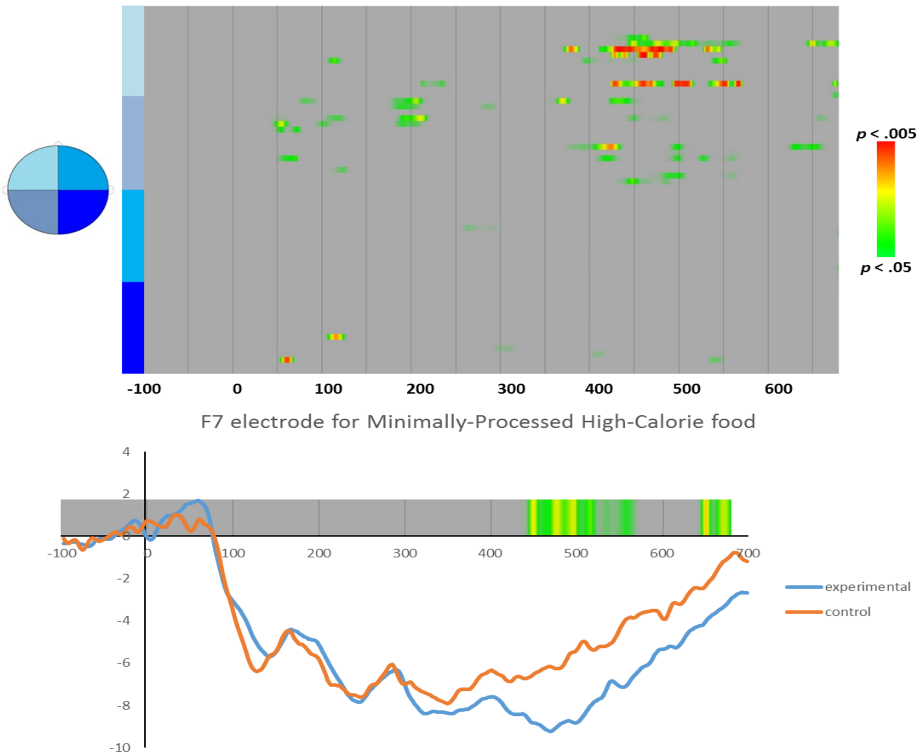


(b)



p < .005
p < .05
-100
0
100
200
300
400
500
600
F7 electrode for Heavily-Processed Low-Calorie food
experimental
control

(c)



p < .005
p < .05
-100
0
100
200
300
400
500
600
F7 electrode for Minimally-Processed High-Calorie food
4
2
0
-2
-4
-6
-8
-10
-100
0
100
200
300
400
500
600
700
experimental
control

(d)

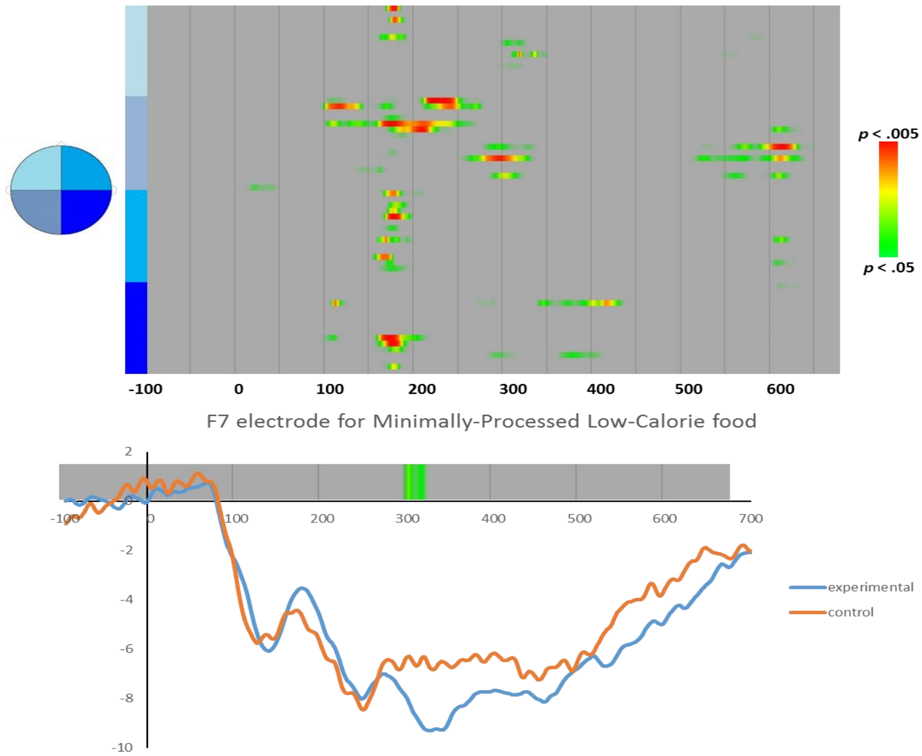

p < .005
p < .05
-100
0
100
200
300
400
500
600
F7 electrode for Minimally-Processed Low-Calorie food
2
0
-100
0
100
200
300
400
500
600
700
-2
-4
-6
-8
-10
experimental
control

Figure 4.1 Examples of image stimuli used in EP and in GNG tasks: (a) Minimally-Processed Low-Calorie food, (b) Heavily-Processed Low-Calorie food, (c) artificial object, (d) Minimally-Processed High-Calorie food, (e) Heavily-Processed High-Calorie food.

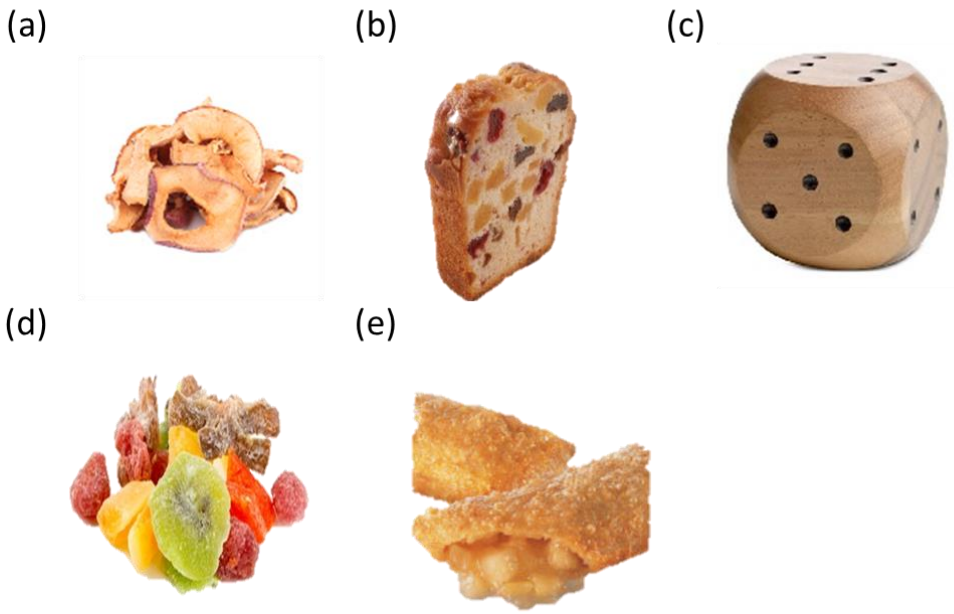


Figure 4.2 Trial structure for the Evaluative Priming Task.

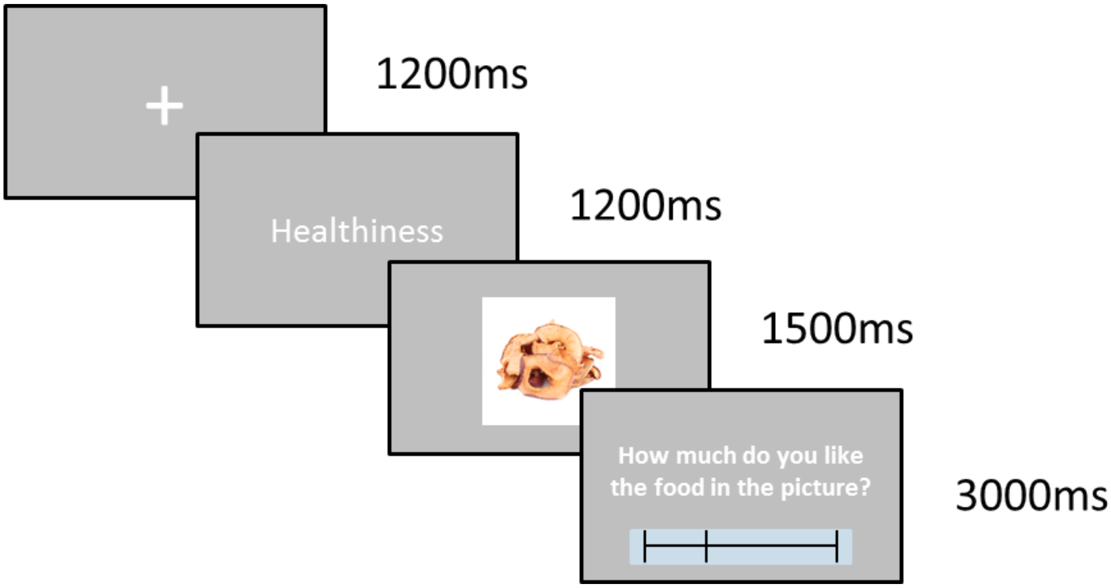


Figure 4.3 Trial structure of the GNG task with food images as NoGo trials (a) and images of artificial object as Go trial (a). Image depicts one NoGo and one Go trial

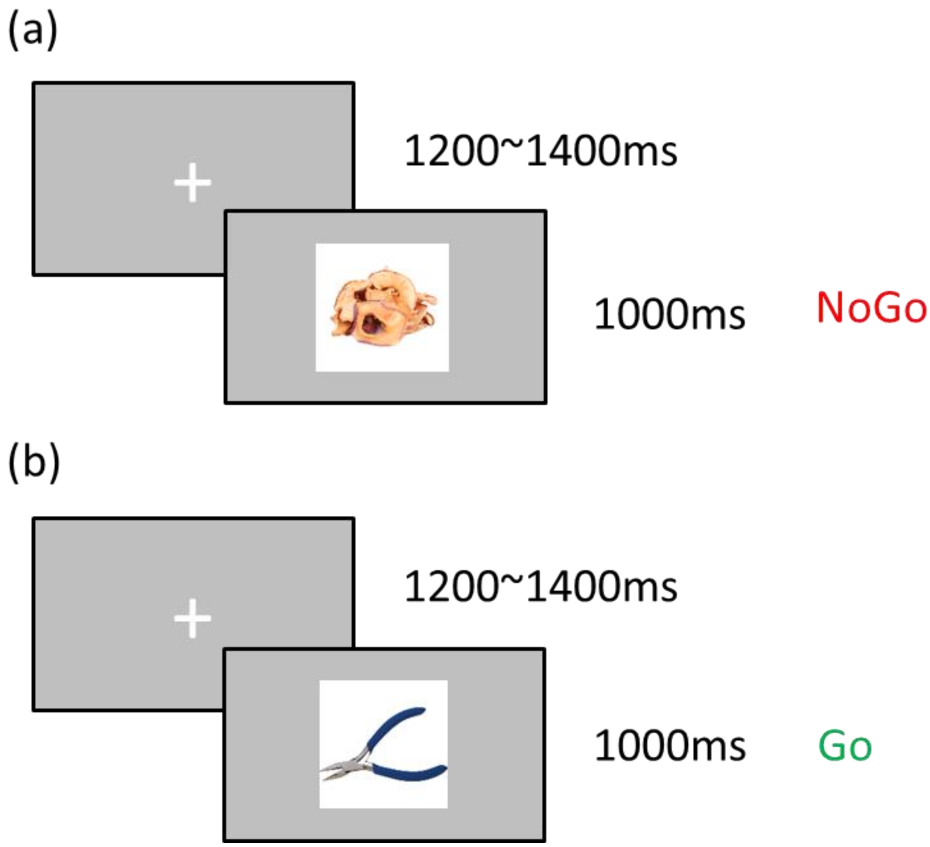
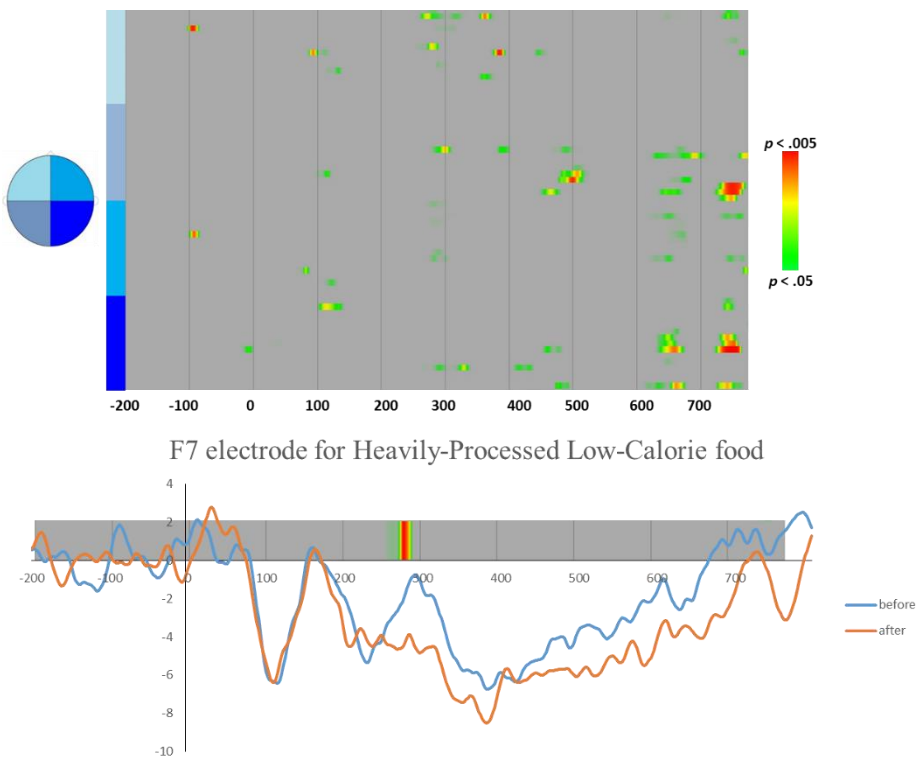
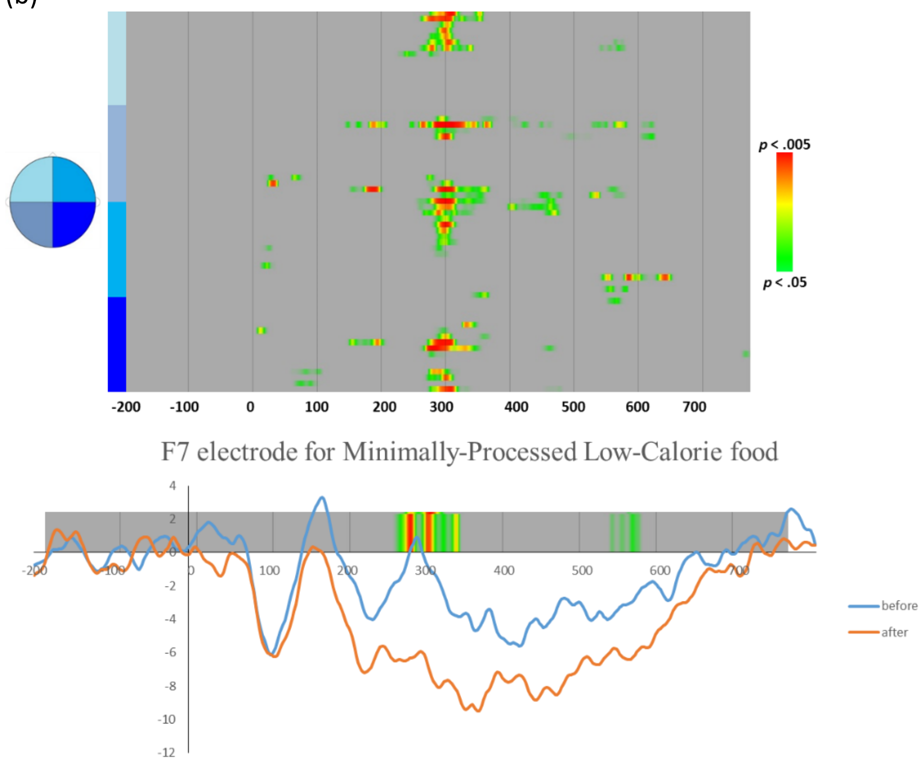


Figure 4.4 Averaged brain waveform at electrode F7 (left DLPFC, BA47/46) for food images with evaluative priming considering also degree of process and calorie for NoGo trials in pre-EP (before) and post-EP (after) GNG tasks. In each sub-figure, the upper part indicate the significant *p*-values of the paired t-test in the whole brain and the lower part indicate the averaged brain waveform for each category of food at electrode F7. More negative N200 amplitudes were consistently found in post-EP GNG task for (a) Heavily-Processed Low-Calorie food and (b) Minimally-Processed Low-Calorie food, but not for (c) Heavily-Processed High-Calorie food and (d) Minimally-Processed High-Calorie food.

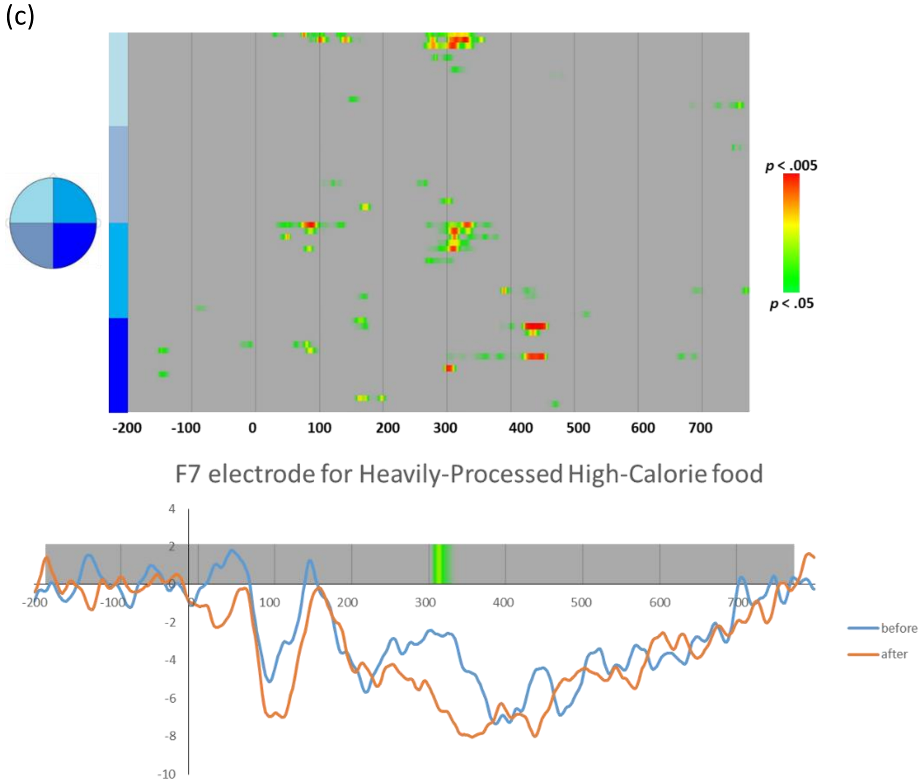
(a)



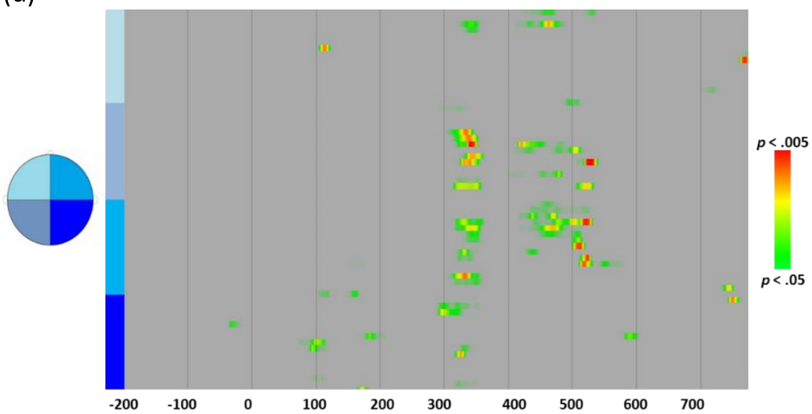
(b)


p < .005
p < .05
-200
-100
0
100
200
300
400
500
600
700
F7 electrode for Minimally-Processed Low-Calorie food
before
after

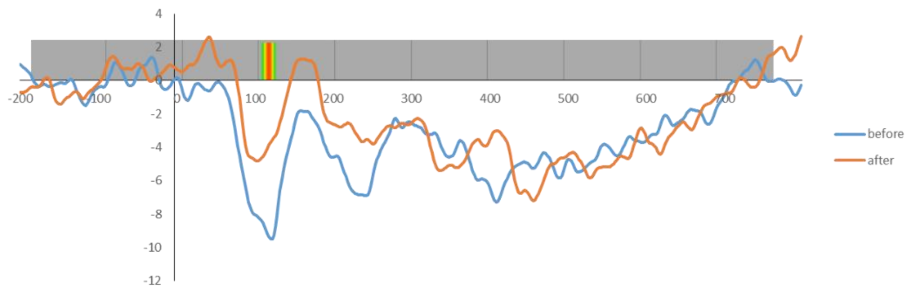
(c)


p < .005
p < .05
-200
-100
0
100
200
300
400
500
600
700
F7 electrode for Heavily-Processed High-Calorie food
before
after

(d)



F7 electrode for Minimally-Processed High-Calorie food



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