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# How brain response and eating habits modulate food energy estimation

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ABSTRACT

The estimates we do of the energy content of different foods tend to be inaccurate, depending on several factors. The elements influencing such evaluation are related to the differences in the portion size of the foods shown, their energy density (kcal/g), but also to individual differences of the estimators, such as their body-mass index (BMI) or eating habits. Within this context the contribution of brain regions involved in food-related decisions to the energy estimation process is still poorly understood. Here, normal-weight and overweight/obese women with restrained or non-restrained eating habits, received anodal transcranial direct current stimulation (AtDCS) to modulate the activity of the left dorsolateral prefrontal cortex (dlPFC) while they performed a food energy estimation task. Participants were asked to judge the energy content of food images, unaware that all foods, for the quantity presented, shared the same energy content. Results showed that food energy density was a reliable predictor of their energy content estimates, suggesting that participants relied on their knowledge about the food energy density as a proxy for estimating food energy content. The neuromodulation of the dlPFC interacted with individual differences in restrained eating, increasing the precision of the energy content estimates in participants with higher scores in the restrained eating scale. Our study highlights the importance of eating habits, such as restrained eating, in modulating the activity of the left dlPFC during food appraisal.

## 1. Introduction

When we consider the same amount of food, for different food types the energy content will change based on their energy density (i.e., the amount of calories per gram). Therefore, it is conceivable that our knowledge concerning the energy density of different foods is used to estimate the actual energy content of different food portions. However, people are generally imprecise in estimating the energy content of foods [1,2,3,4,5,6,7]. This inaccuracy seems to be due mainly to a difficulty in explicitly estimating the energy content of the actual amount of food "on the plate", in other words the portion size [6,7]. Many studies showed that both changes in portion size and in energy density of foods contribute to modulate the amount of energy intake in adults and children, and the contribution of these two factors is independent and additive [8,9,10,11]. However, recent evidence suggests that our brain is able to track the "ideal" portion of the meal [12]. It is therefore of great interest also to determine how these two factors contribute to the estimation of the energy content of different foods.

Given the lack of neuroimaging and neuromodulation studies investigating food energy estimation, the contribution of different brain regions in this cognitive process is poorly understood. One region that was found to be widely involved in food-related decisions is the dorsolateral prefrontal cortex (dlPFC) [13,14,15,16,17,18,19]. The dlPFC is generally involved in cognitive control, integrating multiple sources of information and exerting a top-down control of behavior [20]. In the food domain, the dlPFC is involved in integrating more abstract or long-term attributes of foods (i.e. the information about the level of healthiness of the food) into the choice of which food participants wanted to eat at the end of the experiment [16]. In addition, this region is involved in self-control towards food [15], and in the regulation of cravings [13,14,17,18,19]. It is hypothesized that the dlPFC may have a role in inhibiting the desire towards high-energy or unhealthy food by exerting a modulation over reward-sensitive regions, such as the medial prefrontal cortex or the orbitofrontal cortex [16,18,19]. The process of energy estimation is complex and requires the integration of different pieces of information, concerning the energy density of the food considered and the amount of food shown; thus the dlPFC is a good candidate to support this process. In addition, neuroimaging studies have shown that the activity of the dlPFC is altered both in overweight people and people reporting restrained eating [21,22,23]. Previous

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studies showed increased dlPFC activity in people who showed restraint eating [15,22,23], triggering cognitive control or inhibitory mechanisms when processing food. However, it is still an open question whether higher activation of cognitive control mechanisms translates into more precise food energy estimates. It is therefore interesting to explore the impact of individual differences in the process of energy estimation and in the modulation of the dlPFC activity during this cognitive process.

In the present study, overweight/obese and normal-weight participants, who differed also in their degree of restrained eating, received anodal transcranial direct current stimulation (AtDCS) and sham stimulation in order to modulate the activity of the dlPFC while they performed a food energy estimation task. Participants evaluated food pictures that shared the same energy content (i.e., 200 kcal), but differed in their energy densities and, as such, in the size of their portions. For instance, in order for the two portions of cucumber and chocolate to have the same energy content, the former needs to be larger than the latter, as they two have different energy densities. To provide a precise estimate of the energy content, participants should integrate the information concerning the energy density of the food with the presented portion size. However, if participants' estimates are based on the energy density of foods, it would suggest a difficulty in integrating the information concerning portion size into the energy estimate. Moreover, we hypothesized that, if the dlPFC has a role in supporting the process of energy estimation, we should see that participants increased their ability in estimating the energy content of foods during AtDCS. In fact, this area is expected to be involved in integrating the information concerning the portion size shown with the previous knowledge about the food in terms of energy density. Additionally, we explored the role of individual differences in body-mass index (BMI) and restrained eating in modulating their accuracy in the energy estimation task and the involvement of the dlPFC in this process.

## 2. Materials and methods

### 2.1. Participants

Thirty-seven healthy young females participated in the study. Three of them were excluded because they showed a profile compatible with moderate depression, tested with the Beck Depression Inventory (BDI-II, [24]), three participants were excluded for abnormal food-related behavior, tested with the Eating Disorder Inventory (EDI-3, [25]), and one participant was excluded because she used psychotropic substances.

Therefore, the final sample included 30 participants (see Table 1 for participants' characteristics). Twenty-seven participants were right-handed and three were ambidextrous [26]. None of the participants had a history of neurological or other relevant medical disease, or were under pharmacological treatment that may affect cognitive performance at the time of the experiment. They had normal or corrected-to-normal vision and they did not suffer from daltonism or achromatism. They also did not have specific food restrictions such as vegetarianism or avoidance of specific foods because of religion, allergy or medical conditions. Participants were weighted and measured in their height at the beginning of the experimental session in order to calculate their body-mass index (BMI, in kg/m$^2$), used as an indicator of human body fat [27]. Fifteen participants were overweight or obese (BMI ≥ 25) and 15 participants were normal-weight (BMI from 18.5 to 24.9). Moreover, 19 participants reported to be restrained-eaters, therefore actively trying to restrict or control their dietary intake, whereas 11 participants reported to be non-restrainers, according to the Restraint eating scale-revised (RS-R, [28]; restrained-eaters cut-off score = 13). The RS-R is a ten-item questionnaire used for measuring dietary restraints. Its items are rated on a four- to five-point scale, with a maximum total score of 35. The scale consists of two subscales: weight fluctuation (WF) and concern with dieting (CD). An Italian version of the RS-R had not been yet provided, therefore we used a translated version of the questionnaire.

**Table 1**
Participants' characteristics.

| Characteristic | Value |
|---|---|
| Age (years) | 24.1 ± 3.4 |
| Education (years) | 15.1 ± 2.1 |
| Height (cm) | 164 ± 6.4 |
| Weight (kg) | 70.6 ± 14 |
| BMI (kg/m$^2$) | 26.5 ± 6.2 |
| RS | 13.4 ± 4.1 |

All values are reported as mean ± SD. BMI: body-mass index; RS: restraint eating scale score.

All participants gave written informed consent. The study has been approved by the SISSA Ethics Committee and has been performed in accordance with the ethical standards as laid down in the Declaration of Helsinki and its later amendments.

### 2.2. Stimuli and experimental paradigm

In the main experiment, participants judged 120 pictures of foods ranging from low to high energy density (kcal/g; food energy density range: 0.12–6.91 kcal/g) items. The final 120 food images were selected from a pool of 159 images through a rating performed on 35 healthy participants between 18 and 35 years old (mean age: 26 ± 3 (SD) years; 20 females). The participants enrolled in the pre-selection of the stimuli did not participated in the main experiment. They were asked to write the name of each food shown, to rate the prototypicality of each of the food items on a Likert scale ranging from 1 to 5 points, and to rate on the Likert scale also their eating frequency of each of the foods. Thirty-nine images were excluded because either the naming responses were not consistent across participants or the degree of prototypicality was low.

The final 120 foods were presented each in a portion of about 200 kcal per picture, therefore varying the quantity of food presented depending on the energy density of each food. It is important to note that the portion size of each food shown was adapted in order to present food items containing always 200 kcal per picture and only one portion size for each food was shown. Food pictures were taken from the website: http://www.caloriegallery.com. As specified in the website, the food portions might show mild variations from the exact energy content of 200 kcal.

On every trial, participants saw a fixation cross for 500 ms followed by a picture of one of the food items. Each picture was presented for 2000 ms, and then a question appeared on the screen asking them to judge the energy content of the food ("How energy-heavy do you think this food is?") together with a visual analogue scale with the words "very low" and "very high" at the two extremities (see Fig. 1). The visual analogue ranged from − 460 to 460 pixels in the screen, corresponding to − 122 and + 122 mm. For the analysis and the presentation of the results scale was then converted in units from − 50 to + 50, each unit corresponding to 2.4 mm or 1.2 pixels. We maintained the positive/negative values, as they convey the idea of under- and over-estimation of the energy content. Numerical labels at the extremities were intentionally avoided, as the actual energy content of the items was always constant, i.e., 200 kcal. Participants had to move a slider from the center of the scale to give their response. They were explicitly instructed to estimate the energy content of the food *in the portion* presented to them. Since all food pictures share the same energy content, the optimal behavior would be to evaluate all food items as equal. To achieve this, participants should multiply the portion size with the energy density: energy content (kcal) = portion size (grams) × energy density (kcal/g). Therefore in the present experiment, if participants base their energy estimates on the energy density, it implies that they