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Brain dynamics of meal size selection in humans

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ABSTRACT

Although neuroimaging research has evidenced specific responses to visual food stimuli based on their nutritional quality (e.g., energy density, fat content), brain processes underlying portion size selection remain largely unexplored. We identified spatio-temporal brain dynamics in response to meal images varying in portion size during a task of ideal portion selection for prospective lunch intake and expected satiety. Brain responses to meal portions judged by the participants as 'too small', 'ideal' and 'too big' were measured by means of electro-encephalographic (EEG) recordings in 21 normal-weight women. During an early stage of meal viewing (105–145 ms), data showed an incremental increase of the head-surface global electric field strength (quantified via global field power; GFP) as portion judgments ranged from 'too small' to 'too big'. Estimations of neural source activity revealed that brain regions underlying this effect were located in the insula, middle frontal gyrus and middle temporal gyrus, and are similar to those reported in previous studies investigating responses to changes in food nutritional content. In contrast, during a later stage (230–270 ms), GFP was maximal for the 'ideal' relative to the 'non-ideal' portion sizes. Greater neural source activity to 'ideal' vs. 'non-ideal' portion sizes was observed in the inferior parietal lobule, superior temporal gyrus and mid-posterior cingulate gyrus. Collectively, our results provide evidence that several brain regions involved in attention and adaptive behavior track 'ideal' meal portion sizes as early as 230 ms during visual encounter. That is, responses do not show an increase paralleling the amount of food viewed (and, in extension, the amount of reward), but are shaped by regulatory mechanisms.

1. Introduction

The sight of food triggers a range of physiological and psychological anticipatory responses based on knowledge acquired through past experiences. These responses not only prepare the body for ingestion but serve to guide food choice and intake with little conscious effort. At the neural level, the simple viewing of energy-dense foods elicits strong activations in visual, homeostatic and reward-related areas in comparison to low-energy foods (Frank et al., 2010; Killgore et al., 2003; Siep et al., 2009; Toepel et al., 2009). The most consistent activations across functional magnetic resonance imaging (fMRI) studies are found in the middle occipital gyrus, inferior temporal gyrus, hypothalamus, ventral striatum and middle frontal gyrus (van der Laan et al., 2011). These activations were obtained in normal-weight individuals while viewing food items with high vs. low caloric content with no explicit evaluation of foods requested. Detecting foods rich in energy is essential to ensure nutrition as those foods help to achieve satiety faster and for longer periods than foods poor in energy (Drewnowski and Almiron-Roig, 2010). Responses to the sight of energy-dense foods, especially in the prefrontal region, may further reflect the expected pleasantness of these foods because this brain region is highly responsive to the pleasant taste or flavor of foods (Kringelbach et al., 2003; Kringelbach, 2005; Ohla et al., 2012; Small et al., 2003b; Tzieropoulos et al., 2013). Yet, the practical implications of the greater activations to energy-dense foods on food intake control and in particular on portion size selection remain so far elusive. For example, the abovementioned neuroimaging studies (Frank et al., 2010; Killgore

Abbreviations: CG, cingulate gyrus; EEG, electro-encephalographic; fMRI, functional magnetic resonance imaging; GFP, global field power; IOG, inferior occipital gyrus; IPL, inferior parietal lobe; INS, insula; LAURA, local autoregressive average; MFG, middle frontal gyrus; MTG, middle temporal gyrus; FCQ-S, momentary craving state questionnaires; SPL, superior parietal lobule; STG, superior temporal gyrus; TFEQ-R 18, Three-Factor-Eating questionnaire; VEPs, visual evoked potentials.

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et al., 2003; Siep et al., 2009; Toepel et al., 2009; van der Laan et al., 2011) did not systematically control food portion sizes (Frank et al., 2010; Killgore et al., 2003; Siep et al., 2009; Toepel et al., 2009; van der Laan et al., 2011).

Portion size is yet a crucial determinant of energy balance and weight management (Rolls et al., 2002; Wansink et al., 2005; Wansink and Kim, 2005). Using computer-based tasks with food pictures, a number of studies showed that decisions on portion size are not driven by food energy density or food liking as such, and that participants do not necessarily select the largest portion sizes as their ideal ones (Brogden and Almiron-Roig, 2010; Brunstrom et al., 2010; Brunstrom and Rogers, 2009; Brunstrom and Shakeshaft, 2009; Forde et al., 2011). In other words, it seems that individuals do not select meal portion sizes only for calories or for pleasure. Instead, other factors related to expected post-ingestive effects appear to be key motivators for meal size selection, namely 'expected satiation' (anticipated fullness after consumption) and 'expected satiety' (anticipated fullness between meals). Along these lines, Wilkinson et al. (2012) showed that portion size selection and expected satiety are good predictors of energy intake, thus establishing the practical relevance of computer-based assessments to food intake behavior.

The primary objective of the current study was to identify the spatio-temporal brain dynamics mediating portion size judgment to gain further insight into food intake behavior and control. Responses to visually presented meals of varying portion size were assessed by means of electro-encephalographic (EEG) recordings in 24 normal-weight women during a task of portion size judgment for expected satiety. Stimuli were pictures of 19 meals presented on a computer screen in a range of 11 different portion sizes. EEG data were analyzed using an electrical neuroimaging approach (Michel and Murray, 2012) as a function of individuals' judgments on the presented portion size among the three following forced-choice options: 'too small', 'ideal' and 'too big'. Under an assumption that only the increasing quantity of food viewed modulates brain responsiveness, one would expect to find an incremental increase of responses in the temporo-occipital brain regions involved in visual analysis and categorization within 200 ms after image onset (Busch et al., 2004; Puce et al., 2013), likely paralleled by similar response directions in prefrontal regions due to the reward value to food (Frank et al., 2010; Killgore et al., 2003; Siep et al., 2009; Toepel et al., 2009; van der Laan et al., 2011). In contrast, we hypothesized that an at least partially distinct network of brain regions would be involved in adaptive portion size selections (i.e., greatest responses to the portions judged as 'ideal' relative to those judged as 'non-ideal'). Due to the high temporal resolution of EEG, such response dissociations might not only be observed along a spatial dimension as in functional neuroimaging studies, but also along a temporal dimension with EEG modulations differing in the time domain for the expected effects (i.e., incremental increase vs. highest response to the portions judged as 'ideal'). Secondary objectives of the study were to explore associations between individual's responses to self-selected portion sizes with food intake attitudes such as dietary restraint and tendencies to overeat in emotionally challenging situations. These factors, known to influence brain responses to visual food cues (Meule et al., 2013; Toepel et al., 2012) and decisions on portion size (Brunstrom et al., 2008) in normal-weight individuals may reveal further insights into the brain mechanisms mediating portion size selection.

2. Material and methods

2.1. Study participants

Twenty-four normal-weight women participated in the study. Women were chosen to avoid confounding factors linked to gender differences in eating behavior and neural responses to food cues (Cornier et al., 2010; Rolls et al., 1991; Toepel et al., 2012). They completed the Three-Factor-Eating questionnaire (TFEQ-R 18) (Karlsson et al., 2000) and momentary craving state questionnaires (FCQ-S) (Nijs et al., 2007). Data from the standardized questionnaires were used for secondary data analyses as factors relating to food intake attitudes. All participants were healthy, with no prior history of self-reported head trauma, neurological disorder or diabetes, and were not under medication. All reported not having any history of eating disorders, current diet attempts, food allergies or intolerances and food restriction such as vegetarianism. Other exclusion criteria were pregnancy, breast-feeding, illicit drug consumption and the consumption of more than one alcoholic drink per day. Due to low EEG signal quality of three participants, only the data of 21 women entered the final analyses and their characteristics are summarized in Table 1. The study was approved by the Ethics Committee of the Faculty of Biology and Medicine of the University of Lausanne. All subjects gave written informed consent and received financial compensation for their participation.

2.2. Stimuli

Stimuli were pictures of 19 test meals commercially available and used previously in a consumer study (Forde et al., 2011). Each stimulus was photographed on a standard white plate. Fifty-one color pictures of different 'physical' portions for each meal were used during a prior familiarization session during which pictures were presented with a description label. A subset of 11 pictures for each meal was used for the subsequent EEG session (Fig. 1A). For a given meal, the central picture #25 corresponds to 100% of the portion size as sold. Picture #1 and picture #50 respectively represent 33% and 300% the kcal content of picture #25. Across this range, the portion size and, by extension, the caloric content of pictures, increase in equal logarithmic steps (0.3 log series) based on the originally published method for quantifying expectations of satiety and satiation (Brunstrom and Shakeshaft, 2009).

2.3. Study design and procedure

Participants completed two experimental sessions on different days. They were instructed to have their usual breakfast between 7:00 and 8:00 am and to refrain from eating any food and drinking caffeinated beverages until they arrived in the laboratory between 9:00 and 10:00. Participants were tested individually in a sound-attenuated booth.

During the prior familiarization session, participants performed a computer-based task comprising sequentially: Thirst and hunger ratings, matched fullness task (expected satiation), selection of portion size to stop feeling hungry until an evening meal (expected fullness), food consumption frequency (times per day/week/month/year), food familiarity and expected liking ratings. The exclusive purpose of this session was to familiarize participants with the views of the 19 meals used in the subsequent EEG session. A report on the outcome data is not in the scope of the current report.

During the EEG session, participants first received the following instructions: "You will be presented with a number of food pictures.

Table 1
Participants' BMI and food intake attitudes (N = 21).

		Mean (±s.e.m.)	Range
BMI (in kg/m^2)		21.3 (±0.4)	17.5–26
TFEQ-R 18	Uncontrolled eating score	40.4 (±3.1)	19–67
	Emotional eating score	42.3 (±5.1)	0–78
	Restrained eating score	27.0 (±4.1)	0–56
FCQ-S score		31.8 (±2.0)	16–49