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Neural Responses to Food Pictures and Their Association with Dietary Intake

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ABSTRACT

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BACKGROUND: Food-related visual cues may affect eating behavior and energy intake. The purpose of this study was to determine the neural response to pictures of food and whether or not the neural responses were associated with energy intake. METHODS: Using a cross-sectional design, 60 adults participated in this study. Each participant reported to the laboratory in a fasted state, were fitted with a 128-electrode electroencephalogram (EEG) net, and were shown pictures grouped into three categories: high-calorie foods, low-calorie foods, and distractor pictures. These pictures were shown in random order. Furthermore, participants were shown these pictures in one passive condition and two active conditions (also in random order). The passive condition required participants to view pictures in a relaxed state while neural responses were recorded. The active conditions required participants to be actively engaged with the picture by pressing or withholding a specified button on a keyboard (go/no go task). The active conditions included only high- and low-calorie foods. Event Related Potentials (ERP) of interest were the N2, P300, and late positive potential (LPP). The National Cancer Institute's Automated Self-administered 24-hour Dietary Recall (ASA24) was used to assess energy and macronutrient intake. RESULTS: The N2 amplitude, when amplitude for high-calorie pictures is subtracted from the amplitude of low-calorie pictures, was significantly different for each active condition ($F = 41.23$; $p < 0.0001$). However, neural responses to picture-type for the N2, P300 and LPP were not different ($p > 0.05$). The difference in N2 amplitude, for the high-calorie no go condition that results from the amplitude for low and high-calorie pictures being subtracted from each other, was significantly associated with carbohydrate intake ($r = -0.263$) and significantly predicted carbohydrate intake (regression coefficient = -56.821; $p = 0.043$) but not energy, fat, or protein intake ($p > 0.05$). Neither the P300 nor the LPP was correlated with or predicted energy and macronutrient intake ($p > 0.05$). CONCLUSION: The N2 differentiates depending on the no go stimulus. The difference in N2 amplitude, for the high-calorie no go condition, may be an index of carbohydrate intake. The P300 and LPP do not appear to differentiate between pictures of high- and low-calorie foods, nor do they correlate with energy or macronutrient intake.

Keywords: visual stimuli, food, EEG, LPP, P300, N2, energy intake

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Introduction

The prevalence of obesity in America remains at dangerous levels (Flegal, Carroll, Kit, & Ogden, 2012). Obesity is linked to cardiovascular disease, type 2 diabetes, stroke, dyslipidemia and other chronic diseases (Must et al., 1999). The etiology of obesity is multifactorial; however, food-related environmental stimuli, including visual food cues, may play a role in eating behavior, energy intake, and risk of obesity (Poston & Foreyt, 1999; Weinsier, Hunter, Heini, Goran, & Sell, 1998).

Accordingly, past research has sought to establish a link between visual food cues and predictors of energy intake (de Castro & Elmore, 1988; Drapeau et al., 2007) such as hunger, appetite, and motivation to eat (Linné, Barkeling, Rössner, & Rooth, 2002; Sadoul et al., 2012; Wansink, 2004; Wansink, Painter, & North, 2005). Predominantly, previous studies have utilized subjective assessment measures, such as visual analog scales (VAS) and food motivation scales (FMS) to assess predictors of energy intake (Blundell et al., 2010; Flint, Raben, Blundell, & Astrup, 2000; Rogers & Hill, 1989; Sadoul et al., 2012). Both VAS and FMS have provided foundational information; however, there is inherent error in using subjective measures to assess energy predictors. Therefore, objective tools and measurements are needed to better assess the effect of visual cues on predictors of energy intake.

The electroencephalogram (EEG) is a tool with broad applications, including the ability to objectively assess the neural response to visual food cues. EEG is used to measure electrical potentials generated by apical dendrites in the brain. When such brain changes are time-locked to the presentation of a stimulus or a respons,e and averaged across multiple trials, they are known as event related potentials (ERP) (Hajcak, MacNamara, & Olvet, 2010). There are three ERP components potentially important for determining the neural response to visual food stimuli

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(Jauregui-Lobera, 2012; Leland & Pineda, 2006; Meule, Lutz, Vögele, & Kübler, 2012; Nijs, Franken, & Muris, 2008). First, the P300 waveform, which can be used to measure increased attention and stimulus control (Patel & Azzam, 2005); second, the late positive potential (LPP) waveform, another measure of stimulus control that indicates the use of attentional resources and regulatory factors in the brain (Hajcak, Dunning, & Foti, 2008); and third, the N2 waveform, a measure of response inhibition (Patel & Azzam, 2005).

Pictures of food can be highly arousing and have been found to significantly affect measures of the P300, LPP, and N2 (Blechert, Feige, Joos, Zeeck, & Tuschen-Caffier, 2011; Hanlon, Larson, Bailey, & LeCheminant, 2012; Hoffman & Polich, 1998; Jauregui-Lobera, 2012; Key & Dykens, 2008; Nijs, Franken, & Muris, 2009; Patel & Azzam, 2005). It is less well-known how the brain perceives various categories of food (e.g., high- vs. low-calorie), particularly when examining the N2 response. There is evidence that N2 amplitude is correlated with self-reported eating behaviors (Watson & Garvey, 2013); however, we are unaware of any studies that have sought to measure whether or not these responses to food pictures are associated with or predict energy intake.

This study overcame previous weaknesses in the literature by determining the extent the ERPs noted above differentiate by type of food picture and whether or not they were associated with energy intake. Therefore, the major aims of this study were: 1) to determine the neural responses to pictures of food for the following ERPs in healthy adults: P300 (stimulus control), LPP (attention), and N2 (response inhibition); 2) to determine the difference in neural responses to high-calorie and low-calorie pictures of food in healthy adults; and 3) to determine the association between the neural responses to pictures of food and energy and macronutrient intake in healthy adults. We hypothesized a stronger neural response to high-calorie food

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pictures than low-calorie food pictures in each ERP component. Additionally, we hypothesized that there would be a moderate association between neural responses to visual food pictures and energy intake. In addition, we hypothesized that the strongest correlation between energy intake and ERP components would be for the N2.

Methods

Participants

The Institutional Review Board (IRB) approved this study and all participants provided written informed consent prior to initiation of the study. A sample of participants was recruited from the Department of Psychology's Experiment Management System, called SONA, at Brigham Young University (BYU) and from the BYU community at large. For this study, 26 participants were initially recruited to participate in a pilot study. The pilot study was used to determine if our picture stimulus and timing was producing accurate results with the EEG.

As part of the pilot study, we found that not all pictures could be accurately categorized by picture type. Therefore we removed any picture that could not be accurately categorized by at least 95% of the participants and we also extended the stimulus time for the active conditions by 400 milliseconds (ms) to reduce error in our N2 measure. Testing parameters were found to be reliable and an additional 82 participants were recruited to test the main outcomes of this study. Out of these 82 participants, 6 were excluded for not completing the dietary recalls and 16 were excluded for having unusable EEG data.

Participants were healthy adults between the ages of 18 and 27 y, weight stable (±5 pounds over the previous 6 mo), English speakers, right-handed, and had a BMI of 18.5 kg/m^2 or greater. Participants were excluded from participation if they used tobacco products, were pregnant or lactating, had an abnormal sleep-wake schedule (>1 hour difference in sleep and

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wake times on two or more days of the week) (Bailey et al., 2013), were participating in a commercial weight loss program or extreme diet, had an eating disorder, were unable to exercise, had a neurologic condition such as epilepsy or stroke, had ADHD, had a previous head injury with loss of consciousness, had uncorrected vision difficulties, or had a diagnosed psychiatric condition, or metabolic disease.

Design

This study utilized a within-subjects cross-sectional design to achieve the major aims. Each participant attended a single laboratory session to assess their neural responses to pictures of food. In conjunction with this testing, habitual dietary intake was assessed using online, 24-hour multiple-pass dietary recalls over the course of one week.

During the laboratory session, EEG data was collected to assess the ERP components of interest for each participant during three conditions with the order randomized: 1) a passive viewing of food pictures, 2) active viewing of food pictures in which the go/no go task focused on high-calorie foods as the no go task, and 3) an active viewing of food pictures in which the go/no go task focused on low-calorie foods as the no go task.

For the passive viewing condition, all participants were shown pictures, in random order, from three categories: high-calorie foods, low-calorie foods, and distractor pictures. Pictures were viewed for 2000ms with a short interstimulus gap (500ms) between each picture.

During the active viewing conditions, participants underwent a go/no go task while being presented with pictures of food (high-calorie and low-calorie only). At onset of the go/no go task, pictures were presented for 500ms with an intertrial interval of 1300ms (plus or minus 100ms) (Watson & Garvey, 2013). Participants were instructed to press a specified button on a keypad when the go picture (either high-calorie or low-calorie) was presented, and participants

were told to withhold their response when the no go picture (either high-calorie or low-calorie) was presented. Participants underwent two different active viewing conditions. One in which high-calorie was the no go and one in which the low-calorie was the no go.

Procedures

Screening. All participants were screened by a member of the research team, via telephone, prior to initiation of the study. The researcher asked questions to determine if participants met the inclusion criteria of the study. For qualifying and interested participants, a single laboratory session was scheduled at the Brigham Young University Clinical Cognitive Neuroscience and Neuropsychology Labs in room 136 of the University Parkway Center or in room 1280 of the Spencer W. Kimball Tower.

Laboratory session. All participants reported for their laboratory session at the Clinical Cognitive Neuroscience and Neuropsychology Lab in a fasted state (no eating after 9 PM the night before testing) and after having slept for at least 7 h the previous night. Upon arrival, each participant reviewed and signed the informed consent form. Subsequently, a demographic survey was completed followed by assessment of height and weight, using a wall-mounted stadiometer and calibrated scale, respectively. Participants wore the clothes they arrived in without shoes and extra layer clothing (jackets, coats, sweaters). Body mass index (kg/m^2) was determined using height and weight measures.

Participants were then brought into the room containing the EEG system and given instructions for the subsequent testing procedures. Each participant completed visual analog scales to determine hunger and appetite levels before they began the EEG procedures. Next, each participant was fitted with a 128-electrode Electrical Geodesics, Inc. (EGI; Eugene, OR). EEG net covering the head, and was seated approximately 17 inches from a 17-inch computer

monitor. As noted previously, participants were assessed under each of the following conditions with the order in counter-balanced fashion: passive viewing of food pictures and two active viewings of food pictures.

During the passive viewing condition, participants were shown two blocks of 180 pictures (360 total). During the active viewing conditions, participants were shown two blocks of 100 pictures for the high-calorie no go stimulus and low-calorie no go stimulus (200 total). The primary differences for the active viewing conditions as compared to the passive viewing condition were: 1) that there were no distractor pictures during the active conditions, and 2) participants actively engaged with the picture by pressing a specified button on a keyboard (go/no go task) during the active viewing conditions. Specifically, each participant pressed a button on a keypad with the right index finger when presented with a go stimulus and withheld pressing the button when presented with a no go stimulus.

Following completion of all conditions, participants were instructed on how to complete an online, 24-hour multiple-pass dietary recall by completing one for the previous day. The Automated Self-administered 24-hour Dietary Recall (ASA24) was used. Furthermore, participants were informed they should complete three additional recalls over the subsequent week, including: two week days (Mon–Thurs) and one weekend day (Fri–Sun). All participants did their first dietary recall the day after the laboratory visit; though they were not informed to do the dietary recall until the morning after the visit. Similarly, the next two days were selected at random and participants were contacted by phone the morning after each selected day to complete a recall for the previous day.

Once participants finished their dietary recalls, a member of the research team examined their entries. If average energy intake was not at least 130% of their estimated resting metabolic

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rate (RMR), the participant was contacted to verbally confirm their accuracy or asked to complete additional dietary recalls (Ravussin, Lillioja, Anderson, Christin, & Bogardus, 1986). After accurate completion or confirmation of accuracy of dietary recalls, participants were then given SONA credit or $20 and were finished with the study.

Measurements

Demographic and Descriptive Measures. Demographic and descriptive measures were determined by self-report. Information was collected such as age, race, sex, employment, sleep patterns, medication use, and pregnancy status. Participants were also asked about their breakfast consumption patterns, as well as their video game use.

Visual Analog Scales. VAS were administered immediately prior to the EEG. A VAS asks for self-ratings on a lined scale (10 centimeter in length) with polar statements on each end of the line. For example, for hunger level, on the far right side of the line were the words "very hungry" and on the end of the left side were the words "not hungry." Individuals were asked to mark a vertical line along the continuum that best described how they felt at that time. There were five other questions that used this same procedure that sought to gauge fullness, desire to eat, amount that could be eaten, urge to eat, and preoccupation with thoughts of food. Previously, VAS has been shown to be highly reliable and consistent in populations that all speak the same language. The averaged error rate for VAS is 10 millimeters (10%) (Blundell et al., 2010).

Electroencephalogram. To determine electrical changes in the brain (Hajcak et al., 2010; *Handbook of Psychophysiology*, 2007), EEG data was recorded from 128 scalp sites using a geodesic sensor net and EGI amplifier system (20K gain, nominal bandpass = .10 – 100Hz). EEG has been found to have high test, retest reliability and is stable across age and varying conditions (Willimas et al., 2005). ERPs, or specific EEG waveforms time-locked to a stimulus,

were determined from the EEG. ERPs are labeled based on morphology, scalp topography, timing and reaction to experimental manipulations (Hajcak et al., 2010). This study examined three different ERP's, including P300, late positive potential (LPP), and N2.

P300 is an ERP that was measured during passive viewing of pictures and is an indicator of initial increased attention arousal and valence (Hajcak et al., 2010). The peak in the P300 happens between 300 and 500ms after the presentation of a stimulus. In addition, the amplitude of the LPP (800–1000ms) was determined. The LPP, also measured during passive viewing, is the waveform following the P300 and is an indicator of stimulus control to specific stimuli and may be an indicator of motivation resulting from the stimuli (Hajcak et al., 2010).

The N2 is an ERP that measures the second negative peak that occurs around 180ms after stimulus. N2 measures electrical changes in the frontal part of the brain and may be highly influenced by visual stimuli (Folstein & Van Petten, 2008). From past studies, N2 appears to measures response inhibition and may be a measure of the "nonconscious" choice (Folstein & Van Petten, 2008; Watson & Garvey, 2013). N2 measures response inhibition in that N2 is higher when individuals are presented with stimuli in which they must withhold their response (Folstein, Van Petten, & Rose, 2008). N2 was measured while participants had to actively engage with the food picture and to make a choice as to whether it was high or low energy.

Eye blinks were removed from the segmented waveforms using independent components analysis (ICA) implemented in the ERP PCA Toolkit (Dien, 2010). The ICA components that correlated at 0.9 with the scalp topography of two blink templates—one generated based on the current data and another provided by the ERP PCA Toolkit author—were removed from the data (Dien, Michelson, & Franklin, 2010). Trials were considered bad if more than 15% of channels were marked bad. Channels were marked bad if the fast average amplitude exceeded $100\mu V$ or if

the differential average amplitude exceeded 50μV. Averaged ERPs were stimulus-locked to the picture from 200ms prior to picture presentation and 1000ms poststimulus. We used the 200ms prestimulus window for baseline correction.

Previous research suggests increased ERP reliability when averaging across multiple sensors (Huffmeijer, Bakermans-Kranenburg, Alink, & van Ijzendoorn, 2014). Thus, for the P300 and LPP we averaged across medial-posterior sites just posterior to Pz, including sites 66, 70, 71, 72, 75 (Oz), 76, 83, and 84 (see Figure 1). The P300 was quantified as the mean amplitude from 200ms to 350ms. The LPP was quantified as the mean amplitude from 800ms to 1000ms. For the N2, we averaged across frontal-central sites 6 (FCz), 7, 106, and Cz. The N2 was quantified as the mean amplitude from 200ms to 300ms.

Pictures (stimuli). The number of pictures in each category for the passive condition was based on previous studies (Babiloni et al., 2009; Blechert et al., 2011; Hanlon et al., 2012; Nijs et al., 2008). During the passive viewing condition, participants viewed 2 blocks of 180 pictures (360 total). During the active viewing condition, participants viewed 2 blocks of 100 pictures (200 total) for each go stimulus. Seventy percent of the pictures shown during the active conditions were for the go stimulus and thirty percent were for the respective no/go stimulus. Based on previous studies, the ratio of go to no go should be greater for go and support our procedure (Folstein & Van Petten, 2008; Watson & Garvey, 2013).

For all conditions pictures shown came from a picture set of 114 pictures with three categories that contained 38 pictures each (high-calorie, low-calorie, distractors). Pictures were shown in random fashion for each condition until all pictures had been seen from the 114-picture dataset. The pictures were then shown again in random order until enough pictures had been shown for the requisite block.

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The picture set used for this study was based on a previous study showing they were reliable in eliciting varied cognitive responses from Killgore et al. (2003). The Killgore picture set consisted of 160 pictures, 60 for high-calorie, 60 for low-calorie, and 40 for the distractor pictures (Killgore et al., 2003). During our pilot study we discovered that not all of the pictures from the Killgore study could be accurately identified with their proper category. Only pictures that could be accurately categorized with 95% accuracy from the pilot study were used for the present analysis.

We were left with 38 pictures for each category. One hundred and fourteen pictures from the previous study were used and comprised of, first, high-calorie foods (38)—including subgroups of candy (4), baked goods (8), ice-cream (6), and high-fat restaurant foods (20), and, second, low-calorie foods (38)—including subgroups of vegetables (12) and fruits (28). During the passive viewing condition only, a third category of distractor pictures was shown, including complex, visually appealing distractor pictures (38) of vegetation (5), flowers (25) and minerals (8).

Body Weight and Height. Body weight was assessed using a calibrated scale, accurate to the nearest .01 kg, in the BYU Clinical Cognitive Neuroscience and Neuropsychology Labs. Participants wore the clothes they arrived in to be weighed. They were instructed to remove shoes and outer clothing (jackets, sweaters, coats). Height was measured using a calibrated, scale-mounted stadiometer. Height and weight were necessary in order to be able to determine if BMI played a role in either energy intake or responses to the pictures.

Dietary Recalls. Habitual dietary intake was assessed in order to determine its association with neural responses to the pictures of food. As mentioned previously, the ASA24 was used to assess dietary intake. The ASA24 is a 24-hour, multiple-pass dietary recall and analysis program

developed by the National Cancer Institutes (NCI) Applied Research Program. The NCI recall program was based on the United States Department of Agriculture Multiple Pass Method, which has a standard error of <3% for normal weight individuals as compared to doubly labeled water (Moshfegh et al., 2008). The ASA24 requires participants to record everything they ate or drank over the previous 24 hours. The recall could be accessed at any time of day by a personal computer. Within the program, participants searched for the foods they ate and were then shown pictures of the food in order to ensure they reported the correct food. They could then report portion sizes either by choosing a picture of different portions or by giving the exact size. After participants entered the food they ate and beverages consumed for the entire day, they were asked multiple follow-up questions about their previous day's diet to assess if they recorded everything accurately.

The strengths of using dietary recalls is that they are accessible anywhere that respondents have access to a computer and the Internet. Multiple pass dietary recalls may also help minimize the possibility of underreporting. Dietary recalls are tools that take little time for a participant to complete (low burden), and they provide quick and accurate results for researchers (Norman et al., 2007). There are weaknesses with dietary recalls that stem from individuals' inability to remember everything they ate and the potential for the recall to not contain the foods that individuals had eaten. Other non-NCI recalls have been compared to doubly labeled water (gold standard in calorie consumption) and reported 9–16% in underreporting of energy intake (Trabulsi & Schoeller, 2001).

Analysis

Data analysis for this study used PC-SAS (version 9.3, SAS Institute, Inc., Cary, NC). Alpha was set at $p < 0.05$ and mean ± standard deviation was used to describe ERPs and for all

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other variables of interest. To accomplish the major aims of this study, the General Linear Model was used to determine differences between picture type for the following ERPs: N2 (high-calorie food pictures versus low-calorie food pictures), P300 (low-calorie food pictures versus high-calorie food pictures versus distractor nonfood pictures), and LPP (low-calorie food pictures versus high-calorie food pictures versus distractor (nonfood) pictures). In addition, Pearson correlations (r) were used to determine the relationship among N2 response differences, P300, LPP and habitual dietary intake. Furthermore, linear regression analysis was utilized to determine the extent that the N2, P300, and LPP predicted energy and macronutrient intake. No control influenced the outcomes of the study so they were not included in the analyses below.

Results

Table 1 presents descriptive characteristics of the 60 participants included in the analysis. Data are presented by male, female, or combined for age, years of education, height, weight, BMI, and energy and macronutrient intake. There were 27 men and 33 women who participated. Participants tended to be young and normal weight.

ERP data are presented for each picture category in Table 2. The N2 amplitude, when amplitude for high-calorie pictures is subtracted from the amplitude of low-calorie pictures, was significantly different between each active condition ($F = 41.23$; $p < 0.0001$). However, there was no difference for picture type in either N2 condition (high no go: $F = 1.23$; $p = 0.269$) (low no go: $F = 1.43$; $p = 0.235$). Along with the N2, neither the P300 ($F = 0.12$; $p = 0.883$) nor LPP ($F = 0.51$; $p = 0.602$) responses exhibited any differences by picture type (high-calorie, low-calorie, distractors) ($p > 0.05$).

Pearson correlation coefficients were used to associate ERP responses with energy and macronutrient intake (Table 3). The N2 amplitude, when amplitude for high-calorie pictures is

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subtracted from the amplitude of low-calorie pictures when high-calorie is the no go, was significantly associated with carbohydrate intake (r = -0.263) but not energy, protein, or fat intake. The negative correlation indicates that as N2 amplitude increases, carbohydrate intake decreases. The P300 and LPP were not significantly correlated with energy or macronutrient intake (p > 0.05). Certain VAS and demographic characteristics were significantly correlated with energy and macronutrient intake. Desire to eat (r = 0.345), the amount that could be eaten (r = 0.377), urge to eat (r = 0.277), and BMI (r = 0.294) were correlated with energy intake. Age (r = 0.310) and BMI (r = 0.421) were correlated with protein intake. Desire to eat (r = 0.393), the amount that could be eaten (r = 0.326), urge to eat (r = 0.326), and BMI (r = 0.392) were correlated with fat intake. The amount that could be eaten (r = 0.387) was significantly correlated with carbohydrate intake.

As shown in Table 4, regression analysis revealed that the N2 difference in amplitude when high-calorie foods were the no go is a significant predictor of carbohydrate intake (regression coefficient = -49.9; p = 0.043). In other words, for every one microvolt increase in the N2 difference, carbohydrate intake decreased by 49.9 g. The N2 also trended toward predicting total energy intake (regression coefficient = -316.1; p = 0.091). The N2 difference did not significantly predict protein or fat intake (p > 0.05). The P300 and LPP did not significantly predict energy or macronutrient intake (p > 0.05).

Discussion

The present study (n = 60) examined the N2, P300, and LPP ERPs in response to pictures of food (high- and low-calorie). In addition, we assessed the association among these responses with energy and macronutrient intake. This study showed a difference in the N2 amplitude between the two active conditions. The active condition where high-calorie was the no go was

associated with carbohydrate intake. No other relationships between neural responses and energy or macronutrient intake were found. Thus our hypotheses were only partially supported.

Previous studies that utilized the N2 components have examined neural responses to broad food picture categories. These studies have reported finding a difference between food pictures as one category and a type of control as another; however, our study used high-calorie food and low-calorie food inversely during a go/no go paradigm (Watson & Garvey, 2013) . Our study adds to previous literature by categorizing and comparing pictures of food by high-calorie and low-calorie food instead of food and controls. We found there is no difference between picture type (high- and low-calorie); however, there are differences in amplitude when the high-calorie is the no go compared to when low-calorie is the no go stimulus.

Surprisingly, we did not find a difference in picture type for the P300 and LPP. This is in contrast to other studies (Nijs et al., 2008; Nijs, Muris, Euser, & Franken, 2010). Nijs et al. (2010) found a significantly enlarged P300 and LPP in response to food pictures as compared to controls. We may not have found this difference because we used three categories (high- and low-calorie and distractors) whereas Nijs et al. (2010) used general food pictures and controls.

We hypothesized that ERP components would be associated with energy/ macronutrient intake. This was the most unique aspect of this study because it is the first study to examine this relationship. We found that the N2 difference in amplitude where high-calorie is the no go appeared to have a significant association with carbohydrate intake. We expected the N2 to be more highly correlated with energy or macronutrient intake due to previous findings that it was highly related to external eating behavior questionnaires (Watson & Garvey, 2013).

The go/no go paradigm used while measuring the N2 helps elicit frontal cognitive control and response inhibition (Folstein et al., 2008; Watson & Garvey, 2013). The difference in

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amplitude for the high-calorie no go trial indicates a greater amplitude (inhibition) for high-calorie pictures. When it comes to foods with more calories, more neural resources are recruited to make a decision about the food. This inhibition to high-calorie foods may be why we see the relationship with carbohydrates. The high-calorie foods may require more processing, and in a situation with multiple food choices, the one with more carbs may be consumed less in individuals with high N2 amplitude in response to high-calorie foods.

Beyond neural responses, we found interesting results from the correlational data. Certain VAS (hunger, urge, amount to eat) were significantly correlated with energy and macronutrient intake. This is interesting because it would appear individuals may be effective at self-monitoring their own perceptions of hunger, urge, and how much they want to eat. These VAS measures may be a modest reflection of what someone will eat.

This study highlights the likelihood that eating behavior and energy intake are complex and are not solely a function of neural responses. Although our findings indicate that there may be a relationship between inhibition for high-calorie foods and carbohydrate intake, there are other factors such as social, smell, portion size, and ultimately choice that influence energy intake (Wansink, 2004).

This study has several strengths. It was the first study to directly compare measured ERP components in response to pictures of food and whether those components are associated with energy or macronutrient intake. We randomized the conditions in which participants viewed pictures. Subjects were tested in a free-living environment that increases generalizability of the study. We showed that the N2 component may be a viable waveform associated with carbohydrate intake.

There are also potential limitations in this study. The participants were a homogeneous group of mostly Caucasian (92%), college-aged individuals. The day of the lab visit for all participants was in the morning between 7 and 10 AM. EEG measures may differ for time of day and day of the week. Furthermore, the BMI for this group was in the normal healthy range and we did not compare any other groups, such as obese, with this group. There are inherent errors in using dietary recalls as compared to weighing and food records. Equipment and measuring procedures are also at risk for error.

In conclusion, the N2 may be the best-suited ERP component to measure neural responses from food pictures. It may also reveal that neural activity in response inhibition may be of highest value for EEG studies. It was found to be correlated with high-calorie foods, depending on the no go stimulus, and it was found to predict energy/macronutrient intake. P300 and LPP did not differ for high- versus low-calorie food pictures and did not correlate or predict energy intake. Ultimately, food choices are impacted by more than visual stimuli alone and people still must make a choice. Further research with EEG and food should focus on using the N2 and seek to fill the gaps in this study by examining different times of day for EEG measures as well as measures in different groups, such as the obese, physically active, chronic dieters, etc.

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Table 1. Participant demographic, dietary, and depression characteristics

	Male n = 27	Female n = 33	Combined
Age	21 ± 2.7	19 ± 1.5	19.9 ± 2.3
Years of Education	13.6 ± 2.1	12.4 ± 2.3	12.9 ± 2.3
Height (cm)	176.3 ± 7.8	166 ± 5	170 ± 8.1
Weight(kg)	76.6 ± 22.5	62.6 ± 9.7	68.9 ± 18
BMI (kg/m^2)	24.4 ± 5.8	22.6 ± 2.7	23.4 ± 4.5
Energy Intake (kcal)	2444 ± 745	1805 ± 548	2092 ± 715
Carbohydrate (g)	297.3 ± 90.1	230.9 ± 73.3	260.8 ± 87.1
Fat (g)	97.4 ± 40.9	72.3 ± 27.0	83.6 ± 36
Protein (g)	100.6 ± 66.0	66.0 ± 24.8	81.6 ± 35.8

Data = mean ± standard deviation

Table 2. Difference in neural outcomes by high- and low-calorie pictures of food

	Low Energy	High Energy	Neutral	F	p
N2 Difference (μ)	-0.238± 0.429	0.282 ± 0.459	NA	41.13	<0.0001
N2 – High No Go (μ)	-2.42 ± 2.41	-2.98 ± 2.76	NA	1.23	0.269
N2 – Low No Go (μ)	-2.51 ± 2.28	-2.98 ± 2.41	NA	1.43	0.235
P300 (μ)	5.940 ± 3.99	6.272 ± 4.367	6.258 ± 4.492	0.12	0.883
LPP (μ)	1.168 ± 2.053	0.779 ± 2.229	0.962 ± 2.302	0.51	0.602

Data are mean ± standard deviation

NA = not applicable.

N2 Difference = The amplitude when amplitude for high-calorie pictures is subtracted from the
amplitude of low calorie pictures.

N2 – High No Go = The active condition in which low-calorie is the no go stimulus.

N2 – Low No Go = The active condition in which low-calorie is the no go stimulus.

Table 3. Pearson r correlations for EEG, VAS and demographic measures

	Mean	Kcal	Protein	Fat	CHO
			Pearson r correlations		
N2 Diff. High No Go(μ)	0.28 ± 0.46	-0.118	0.007	0.003	-0.263**
N2 Diff. Low No Go (μ)	-0.23 ± 0.43	-0.061	-0.088	-0.092	-0.003
P3 Neutral (μ)	6.3 ± 4.5	-0.037	0.005	-0.038	-0.055
P3 Low Calorie (μ)	5.9 ± 4	-0.074	-0.020	-0.062	-0.010
P3 High Calorie (μ)	6.3 ± 4.3	-0.065	-0.026	-0.059	-0.084
LPP Neutral (μ)	0.96 ± 2.3	-0.055	0.008	-0.033	-0.101
LPP High Calorie (μ)	0.78 ± 2.2	0.092	-0.044	-0.083	-0.103
LPP Low Calorie (μ)	1.17 ± 2.05	-0.135	-0.061	-0.132	-0.139
Hunger*	4.8 ± 2.2	0.181	0.155	0.247	0.070
Fullness*	2.7 ± 2	-0.078	-0.077	-0.095	-0.05
Desire to eat*	4.9 ± 2.2	0.345**	0.247	0.393**	0.241
Amount can eat*	6 ± 1.7	0.377**	0.218	0.326**	0.387**
Urge to eat*	4.8 ± 2.2	0.277**	0.226	0.326**	0.173
Preoccupation with Food*	3.6 ± 2.2	0.090	0.113	0.113	0.025
Age	19.9 ± 2.3	0.209	0.310**	0.230	0.083
BMI (kg/m^2)	23.4 ± 4.5	0.294**	0.421**	0.392**	0.059

Data are mean ± standard deviation

N2 Diff. High No Go = When amplitude for high-calorie pictures is subtracted from the

amplitude of low-calorie pictures when high-calorie is the no go stimulus.

N2 Diff. Low No Go = When amplitude for high-calorie pictures is subtracted from the amplitude of low-calorie pictures when low-calorie is the no go stimulus.

*Scale is 1-100 mm. VAS questions in which participants mark on a line 100mm in length as to how they felt about the following questions from least to most:

How hungry do you feel?

How full do you feel?

How strong is your desire to eat?

How much do you think you could eat now?

What is your urge to eat?

What is your preoccupation with thoughts of food?

**Indicates statistical significance

Table 4. ERPs as predictors of energy intake and macronutrient intake.

Predictor	Energy Intake		CHO		Fat		Protein	
	RC	p	RC	p	RC	p	RC	p
N2								
High No Go	-183	0.371	-49.9	0.043	0.2	0.984	0.6	0.956
Low No Go	-101	0.646	0.7	0.979	-7.7	0.485	-7.3	0.503
P300								
High-calorie	-11	0.619	-1.7	0.523	-0.5	0.656	-0.2	0.842
Low-calorie	-13	0.577	-2.2	0.448	-0.6	0.640	-0.2	0.877
LPP								
High calorie	-29	0.485	-4.0	0.435	-1.3	0.527	-0.7	0.740
Low calorie	-47	0.304	-5.91	0.289	-2.3	0.313	-1.1	0.641

N2 High No Go = The amplitude when amplitude for high-calorie pictures is subtracted from the amplitude of low-calorie pictures when high-calorie is no go stimulus.

N2 Low No Go predictor = The amplitude when amplitude for high-calorie pictures is subtracted from the amplitude of low-calorie pictures when low-calorie is no go stimulus.

RC = Regression Coefficient. Regression coefficients represent the change in the energy or macronutrient for every 1 microvolt change in the ERP.

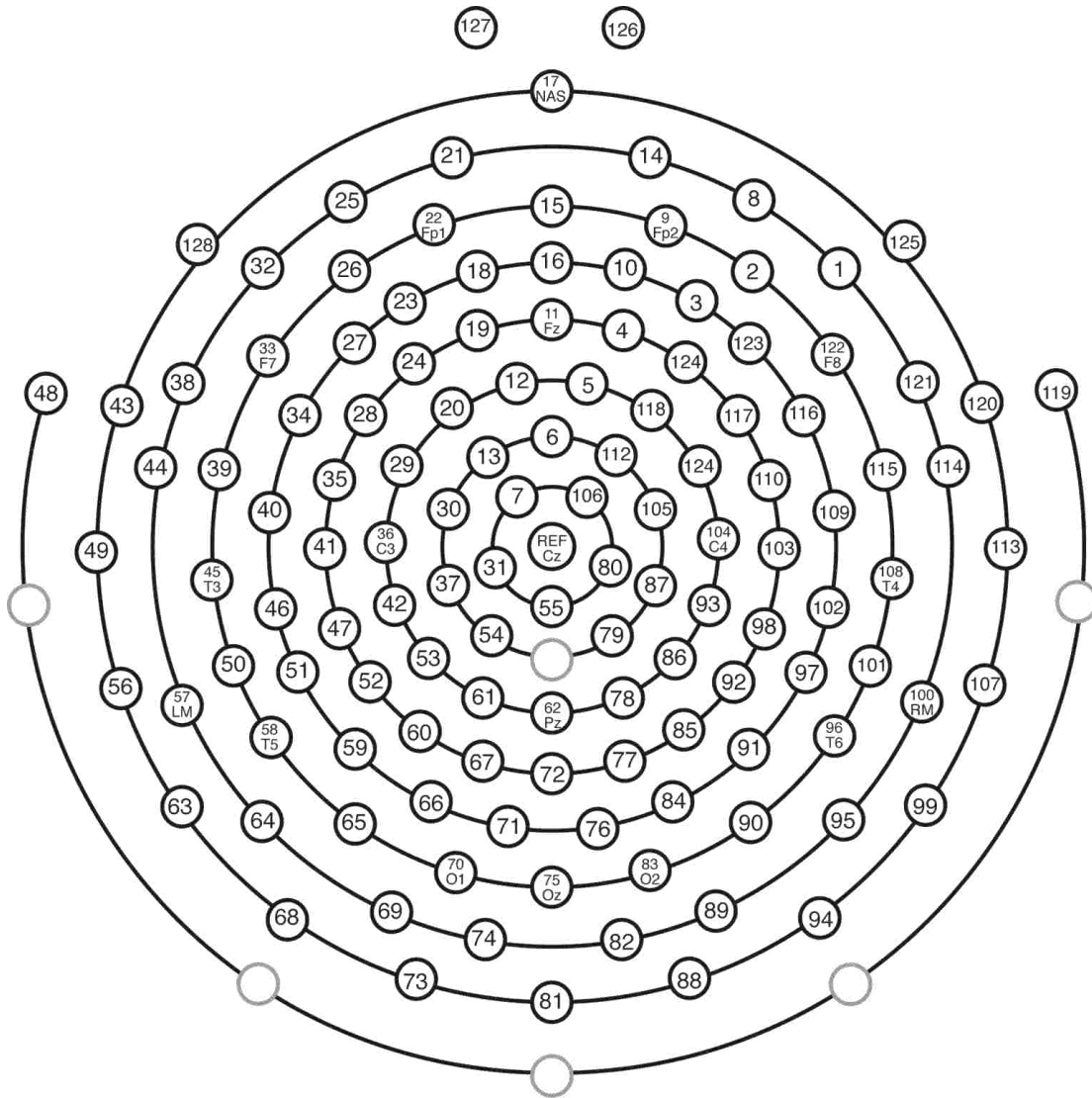P300 and LPP predictor = The average response to the food category in microvolt

Figure 1. EEG Scalp Electrode Site Map