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Neural Reactivity to Visual Food Stimuli in the Morning and Evening:

An fMRI Study in Women

Travis Masterson

A thesis submitted to the faculty of  
Brigham Young University  
in partial fulfillment of the requirements for the degree of

Master of Science

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## ABSTRACT

### Neural Reactivity to Visual Food Stimuli in the Morning and Evening: an fMRI Study in Women

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**Background:** Visual food stimuli have been shown to influence desire to eat and may influence overall energy intake. The purpose of this study was to determine the influence, if any, that time of day has on the neural response to visual food stimuli, as measured by functional magnetic resonance imaging (fMRI). **Methods:** Using a crossover design, 15 healthy women were scanned using fMRI while presented with low- and high-energy pictures of food, once in the morning (6:30–8:30 am) and once in the evening (5:00–7:00 pm). Diets were identical on both days of the fMRI scans and were verified using weighed food records. Pictures used were based on the work of Sweet et al. (2012). Visual analog scales were used to record subjective perception of hunger and preoccupation with food prior to each fMRI scan. **Results:** Nine brain regions showed significantly higher activation for high energy stimuli compared to low energy stimuli ( $p < 0.05$ ). Six areas of the brain showed lower activation in the evening to both high and low energy stimuli including parts of some reward pathways ( $p < 0.05$ ). Subjectively, participants reported no difference in hunger by time of day ( $F(1, 14) = 1.84, p = 0.19$ ), but felt they could eat more ( $F = 4.83, p = 0.04$ ) and were more preoccupied with thoughts of food ( $F = 5.51, p = 0.03$ ) in the evening compared to the morning. **Conclusions:** High energy food stimuli tended to produce greater fMRI responses than low energy foods in specific areas of the brain, regardless of time of day. However, evening scans showed a lower response to both food categories in some areas of the brain compared to the morning. These data may have clinical implications for fMRI measurement and practical implications for sensitivity to food cues and eating behavior.

**Keywords:** visual stimuli, food, neural reactivity, fMRI, time, morning, evening

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## Introduction

Food-seeking and eating behaviors are complex but may be influenced by time of day.<sup>1,2</sup> For example, there is evidence to suggest that the evening meal is the largest of the day and is important in determining overall energy intake.<sup>1</sup> Similarly, a recent study suggested that in young men, 26% of total energy intake occurred after the evening meal and by eliminating the amount of energy consumed after 7 pm, total daily intake was reduced by ~244 kcal/d.<sup>2</sup> Nevertheless, why or how the evening hours reportedly influence eating behavior is poorly understood and not well-investigated. This path of scientific inquiry is important and has practical implications with regard to weight management and obesity.<sup>3</sup>

Admittedly, food-seeking and eating behaviors can be influenced by a variety of environmental cues, as well as social, behavioral, and individual factors.<sup>4-7</sup> In addition, many adults live in an environment where there is easy access to inexpensive, high-energy foods. Of these influences, visual cues may have a particularly potent effect on dietary choices.<sup>8-10</sup> This is evidenced by the degree of food advertisements expertly and strategically presented to potential consumers throughout their day.<sup>11</sup> Accordingly, a growing body of research has begun to objectively examine the influence of visual food cues by specifically measuring what is going on inside the brain when presented with food stimuli (pictures of food).<sup>8,9,11,12</sup>

Previous research has shown higher activation in areas of the brain related to reward and motivation when participants are presented with food stimuli.<sup>9,13,14</sup> In addition, the response to high-energy stimuli compared to low-energy stimuli seems to be greater.<sup>9,13,14</sup> It has been suggested that this reward response may potentially motivate a person to consume more food.<sup>15</sup> In this context and given the theory that food intake increases in the evening, it would be valuable to know to what extent the evening hours influence neural responses to visual food

stimuli compared to other times of the day. To our knowledge, there are no studies that have done this.

Functional MRI (fMRI) is recognized as one of the most effective ways to examine metabolic changes in the brain as it processes various types of stimuli.<sup>16</sup> It has become a widely used and accepted measurement tool in the human neuroscience and psychology fields.<sup>16</sup> Functional MRI is an objective and powerful assessment tool that provides good temporal and spatial resolution to examine neural responses to a stimulus.<sup>16</sup> Functional MRI is based on measuring the signal change produced by the blood oxygenation level dependent response (BOLD), i.e., the hemodynamic response in which blood, a paramagnetic substance, is delivered to specific areas of the brain that are activated by a given stimulus thus increasing the signal output measured by the MRI computer.

With the increasing use of fMRI, questions of clinical relevance and measurement protocol arise. Should time of day affect neural responses, this could influence what are considered “best practices” for certain fMRI measurement protocols used by clinicians. Thus, examining the relationship between neural responses to visual food stimuli and time of day has not only practical implication but clinical implication as well.

Presently, there are significant gaps in the scientific literature regarding the practical and clinical implications of fMRI responses to visual food cues at different times of the day. First, fMRI studies of visual food stimuli are few in number. Second, we are unaware of a single fMRI study that has examined neural reactivity to food stimuli in the evening or compared neural responses by time of day. This study attempts to add to the scientific literature by utilizing fMRI to: first, compare the neural response to visual food pictures in the morning vs. evening; and second, determine differences in the responses between low-energy and high-energy categories

of food. We hypothesized that the neural response to visual food stimuli will be greater in the evening as compared to the morning in areas of the brain such as the ventral tegmental area, the nucleus accumbens, the prefrontal cortex, amygdala, and the hippocampus as these areas relate to reward and attention. Secondly, we believed there would be a stronger neural response to high-energy foods as opposed to low-energy foods regardless of time of day.

## **Methods**

### *Study Design*

The Institutional Review Board at Brigham Young University approved this study and all participants gave written informed consent prior to beginning. Fifteen premenopausal women were recruited for this study to complete two experimental conditions. The conditions were counterbalanced and the order was determined at random. During the first experimental condition (Morning Condition), the neural response to pictures of food was assessed in each participant between the hours of 6:30–8:30 am. During the second experimental condition (Evening Condition), the neural response to pictures of food was assessed in each participant between the hours of 5:30–7:30 pm. During each condition, blood oxygen level dependent (BOLD) neural response to pictures of food was recorded using fMRI scans. The food pictures used contained a mix of high energy-dense/highly palatable foods, low energy-dense foods, blurred versions of the food pictures (used as a control condition to factor out visual processing), and visually complex pictures of vegetation and minerals (used as a second control condition to factor out neural activation to visually complex stimuli).

Except for the time of day of the fMRI scans, the Morning and Evening Conditions were as similar as possible. Participants were scanned on the same day of the week with a separation of one week between conditions. Participants were instructed to follow the same daily schedule

on the days of both conditions. In addition, assessments were not conducted during holidays, vacations, or any break not typical of the participant's normal schedule. For both conditions, participants were required to have slept at least 7 h the night before, discontinued eating the previous night by 8 pm, and refrained from vigorous-intensity exercise, caffeine, or alcohol consumption for at least 24 hours prior. During both conditions, participants consumed their same self-selected diet by total calories, total volume, and nutritional composition. Additionally, each meal was eaten at approximately the same time on both days.

### *Participants*

Participants were weight stable ( $\pm 5$  lbs), had normal sleep patterns, and were regular consumers of breakfast, lunch, and dinner over the previous six months. Participants were excluded if they were claustrophobic or if they had night eating syndrome (NES). The NES criteria used are those proposed by Stunkard et al.<sup>17</sup> Additionally, participants were excluded if they were highly active ( $> 4$  times and 20 min per bout of vigorous activity per week), competitive or collegiate athletes (including marathon runners and triathletes), actively dieting or participating in any sort of commercial weight management program, had a metabolic disease, neurological or psychiatric disorder, eating disorder, used tobacco products, abused alcohol (no more than three standard drinks in a day or more than seven standard drinks in a week), were pregnant or lactating, or were otherwise incompatible with MRI (e.g., have pacemakers or recent tattoos). Participants were compensated \$50 (\$25 per scan) for their time and participation.

### *Procedures*

For qualifying participants, assessments began with a visit to the Body Composition Laboratory and two visits to the MRI Research Facility, both facilities are located at Brigham Young University. On the initial visit, each participant received an overview of the study

requirements, were screened for safety and informed of the protocol of the fMRI facility, and gave their informed consent to participate in the study. Subsequently, each participant was assessed for body composition, height and weight and was instructed on how to complete a computerized, multiple-pass, 24-hour dietary food recall by completing one for the previous day with the aid of study personnel. Furthermore, participants were instructed that they should eat an identical diet on the day of both fMRI scans and were taught how to select foods based on their 24-hour recalls that best represented their typical dietary intake. Between the first and second visits, participants were required to complete three additional online 24-hour dietary recalls (days were determined randomly and included one weekend day). As noted above, using a counter-balanced design, the order of conditions was randomly selected. This was done using a stratified randomization protocol to ensure that an equivalent proportion of participants would start in the Morning Condition and the Evening Condition. Both the participant and the research assistant were blinded prior to the randomization being revealed. The condition was revealed to both at the end of the first visit.

On the second visit, participants presented at the MRI research facility to be scanned in their first condition (Morning or Evening). Subsequently, participants recorded their food consumption by completing a weighed food record for all food consumed on that day. Weighed food records were used on the day of the scans rather than 24-hour recalls ensuring that the exact same foods and amounts were consumed on both days, since variance in content or energy profile could affect study outcomes. Between the second and third visits, participants completed 3 additional randomly-determined dietary recalls (including one weekend day). On the third visit (on the same day of the week as the second visit), participants were scanned under their second

condition (the condition not received previously). Participants consumed an identical breakfast and lunch at the same time of the day.

For the Morning Condition, participants were scanned between 6:30–8:30 am in a fasted state. Participants subsequently consumed their typical breakfast before 9:30 am and their typical lunch between 11:30 and 1:00 pm. These meal timeframes were designed to mimic normal meal hours and allowed for a significant delay between the lunch and evening meal (~5–6 h). Snacking or food consumption after lunch was not allowed. For the Evening Condition, participants consumed the same breakfast and lunch at the same time of day as during the Morning Condition, but completed their fMRI scan between 5:30–7:30 pm and prior to their evening meal. For the evening meal of both conditions, each participant weighed and recorded their dietary intake.

#### *Body Composition*

During the initial meeting with the participant, body composition was assessed using dual-energy x-ray absorptiometry (DXA). The GE Lunar iDXA (GE Lunar, Madison, WI) is the model used in this study. The DXA has been shown to be a valid and widely-accepted method of body composition measurement.<sup>18</sup> Height was measured using a digital stadiometer and weight was measured on a standard scale.

#### *Dietary Intake*

Habitual dietary intake of participants was assessed using an online multiple-pass 24-hour recall (Automated Self-Administered 24-hour Dietary Recall, 2014, Washington D.C.) during their first visit, and 3 additional days, determined randomly, during the week prior to the first condition and during the week prior to the second condition for a total of 7 recorded days. Studies have shown the validity of online 24-hour recall tests and have even suggested that they

are superior to paper food frequency questionnaires.<sup>19</sup> Studies have shown computerized recalls to have relatively high accuracy,<sup>20 21</sup> as well as having the advantage of reducing the burden on participants and researchers compared to other dietary assessment methods.<sup>22</sup>

On the day of the first condition, participants were encouraged to consume a breakfast and lunch based on the information from their dietary recalls (see above), including: 1) similar macronutrient content; 2) similar energy content; and 3) similar amounts of foods from specific food groups and was tracked using a weighed food log. A portable weigh scale (Ohaus, Parsippany, NJ) and a blank food record was provided in order to increase precision of recording. On the subsequent condition, each participant consumed foods identical to their first condition, including amounts. Finally, the food log results were then entered into ESHA Food Processor software (ESHA, Salem, OR) for analysis.

#### *Visual Analog Scales*

Prior to fMRI scanning on each condition, participants were given a visual analog scale (VAS), which asked several questions including: 1) How hungry do you feel, 2) How full do you feel, 3) How strong is your desire to eat, 4) How much do you think you could eat now, 5) What is your urge to eat, and 6) What is your preoccupation with thoughts of food? These questions have been previously used in other studies.<sup>23</sup> Furthermore, VAS have been shown to be a quick and accurate way to obtain quantifiable participant feedback.<sup>23,24</sup> Individuals answered these questions by making a mark on a 100 mm straight line, the two extreme answers to each question are placed on opposite ends of the line. Measurements from the extreme answers provided participative measures of how strongly a participant felt about the specific question towards one extreme or the other.

### *Functional MRI Stimuli and Behavioral Procedure*

Pictures used for scanning (and the number of pictures in each category) were comprised of four groups: 1) low-energy foods (n = 120), including sub groups of vegetables (n=34), fruits (n = 74), fish (n = 6), and whole grains (n = 6); 2) high-energy foods (n = 120), including sub-groups of candy (n = 10), baked goods (n = 32), ice cream (n = 18), and high-fat restaurant foods (n = 60); 3) complex visually appealing distractor pictures (n = 120), including sub groups of vegetation (n = 16), flowers (n = 80) and minerals (n = 24), in order to control for visual richness and general interest; and 4) blurred pictures (n = 360) correlating to each picture used from all of the above categories were also shown to control for visual stimulation due to the visual complexity and wavelengths of the colors presented by each picture. Forty of the pictures from each group were selected from a previous study that has shown high test-retest reliability.<sup>13</sup> The other eighty pictures selected for each group were similar foods and presentations of that food from the original study.<sup>13</sup> One group of 60 pictures from each subset (low-energy, high-energy, and distractor) was randomly selected for the first test visit. The remaining group of 60 pictures from each group was used in the subsequent visit. Equal numbers of pictures from each subgroup were present in either group of 60 pictures. This was done to ensure that each picture used in the scans maintained a novel effect for the participant while at the same time it assured that differences in scans were not due to the participant being presented with personally appealing or unappealing foods during one condition, as all pictures had an equivalent picture in either group.

Participants were shown random blocks of photos of the same type of stimuli with ten photos in each block; blocks were alternated with blocks of randomized blurred images. During each block, the participants were asked to respond to a question by pressing a button with their right hand. For food items, participants were asked to decide whether the picture was a breakfast



item or a dinner item. For distractor stimulus, participants were asked whether the picture was predominantly warm or cool in color. For blurred stimulus pictures, participants were asked to press the button every time the photo changed. This task was used to help eliminate mind wandering by keeping the participant on task and engaged. Each picture was projected for 2.5 seconds with an inter-stimulus interval of 0.5 seconds. Participants were presented with a total of 36 blocks consisting of 10 photos each over the two conditions.

### *MRI Data Acquisition*

MRI data were acquired using a Siemens TIM-Trio 3.0T MRI scanner (Siemens Trio, Erlangen, Germany). A 7-minute high resolution T1-weighted MPRAGE structural scan with the following parameters was collected from each participant at the beginning of the scan session: TE = 2.26 ms; T = 1900 ms; flip angle = 9°; matrix size = 256 × 215 mm; field of view = 218 × 250 mm; 176 slices; slice thickness = 1mm; voxel size = .977 × .977 × 1; 1 total acquisition.

Participants then completed two functional runs with each run lasting approximately 10 min with a small break in between; total time in the scanner was approximately 30 min. We collected T2\*-weighted images using the following parameters: TE = 28 ms; TR = 2000 ms; flip angle = 90°; matrix size = 64 × 64; field of view = 220 × 220 mm; 40 slices; slice thickness = 3 mm; voxel size = 3.4 × 3.4 × 3 mm; 270 total acquisitions.

### *Data Analysis*

The MRI data were preprocessed and analyzed using the Analysis of Functional NeuroImages (AFNI) suite of software.<sup>25</sup> All functional runs were time shifted, corrected for participant motion, and spatially filtered. Structural scans were co-registered with the functional scans. Initial spatial normalization was accomplished by aligning structural scans to the atlas of Talairach and Tournoux (1998). Further normalization was accomplished by aligning all

structural scans to a custom template using Advanced Normalization Tools software (ANTs; Version 1.9; <http://sourceforge.net/projects/advants/>).<sup>26-29</sup> A regression analysis was conducted on the functional data set in AFNI using 3dDeconvolve. Six regressors coding for motion (three translations and three rotations) were included as conditions of no interest. Three additional regressors were created coding for high-energy blocks, low-energy blocks, and control stimuli blocks. Blocks were modeled by convolving the standard hemodynamic response function with a 30-second boxcar function. The blurred image blocks were used as an implicit baseline in the model. Data were then spatially normalized and a group analysis was performed. The conditions of interest were: Morning low-energy, Morning high-energy, Evening low-energy, Evening high-energy. The distractor picture data were used to assure that the reactions were not similar to nonfood items.

For the group-level analysis, we conducted a 3-way ANOVA with scan time (morning, night) and stimulus type (high-, low-calorie, and distractor) as fixed factors and participants as a random factor. The results of these tests yielded a threshold with a specific voxel-wise p-value of  $p < .001$  and 40 contiguous voxels for the spatial extent threshold, which was determined by running a Monte Carlo simulation to obtain an overall p-value of  $p < .05$  assuring that results were not simply due to noise. Finally, threshold statistical maps were subjected to visual inspection to find meaningful effects. Data within the areas of activation were analyzed in SPSS.

Regression analyses, condition differences, and Condition x Food Type interactions were conducted in SPSS. Habitual food intake, participant demographics, and VAS scale scores were analyzed with the results of the fMRI in areas of activation for main effect of time and main effect of stimulus looking for correlations using the statistical software PC-SAS (version 9.3,

SAS Institute, Inc., Cary, NC). Statistical significance for all results were  $p < 0.05$ . Paired t-tests were used to determine differences in VAS scores and energy intake between conditions.

## **Results**

### *Participant Characteristics*

Characteristics of the 15 participants are summarized in Table 1. The average age of the women was  $23.33 \pm 1.02$  y and the average BMI was  $22.93 \pm 2.69$  kg/m<sup>2</sup> with an average body fat percentage of  $32.46 \pm 5.99\%$ . Participants were 13 Caucasian, 1 Asian and 1 Hispanic.

### *Habitual Intake and Scan-Day Intake*

Analysis of the habitual intake recorded by the seven 24-hour recalls showed the average caloric profile of the participants was  $1953 \pm 466$  kcal. When intake was recorded using the weighed food logs participants reported  $2009 \pm 544$  kcal for the morning condition and  $1975 \pm 504$  kcal for their evening condition. When analyzing the habitual intake to the weighed food records the results show that participants did not deviate more than 2% from their caloric profiles on their scan days. The difference between caloric profiles on the scan days was nonsignificant between conditions ( $F(1, 14) = 1.16, p = 0.78$ ).

### *Visual Analog Scales*

Table 2 reports the visual analog scale responses to questions in the morning and the evening. Interestingly, participants reported no difference in prescan hunger, fullness, desire for food, and urge to eat between conditions ( $p > 0.05$ ). However, significantly higher responses were observed in the evening when asked the questions, “How much to you think you could eat now?” ( $F(1, 14) = 4.83, p = 0.04$ ), and “What is your preoccupation with thoughts of food?” ( $F(1, 14) = 5.51 p = 0.03$ ).

### *Functional MRI*

The ANOVA revealed several significant clusters that demonstrated main effects for time of day and for stimulus type as described below. However, no significant brain activations were found for a direct interaction between time of day and food stimulus type ( $p > 0.05$ ).

#### *Main Effect of Time of Day (Morning vs. Evening)*

Table 3 reports the areas of significant activation when considering the main effect of time of day. Figure 1 depicts the regions in axial slices, again color-coded by region. In each region, including left putamen, right lingual gyrus, right middle temporal gyrus, right medial temporal lobe (parahippocampal cortex and hippocampus), right middle occipital gyrus, and right ventral striatum and amygdala, fMRI activation was greater in the Morning Condition than in the Evening Condition. In the right lingual gyrus, right middle temporal gyrus, right medial temporal lobe (parahippocampal cortex and hippocampus), right middle occipital gyrus, and right ventral striatum and amygdala areas there are main effects of both time and stimuli. The results show that high-energy foods still produced a significantly greater response in these areas than did low-energy foods. However, there is no interaction between time and stimulus in any of the reported areas. Figure 2 shows line graphs representing the activation of stimulus type in morning and evening.

#### *Main Effect of Food Stimulus Type (High- vs. Low-Energy)*

Table 4 reports the areas of significant activation when considering the main effect of stimulus and Figure 3 depicts these regions in axial slices with each region shown as a different color. In each region, including right middle occipital gyrus, left lingual gyrus, bilateral fusiform gyrus and parahippocampal cortex, right superior parietal lobule, and bilateral medial frontal gyrus, activity was greater for the high-energy food stimuli than for the low-energy food stimuli.

None of the reported areas show a significant main effect for time of day except for the right fusiform gyrus/parahippocampal cortex. There are no reported interactions between time of day and stimulus. Figure 4 depicts line graphs representing the activation of the main effect of stimulus type. There were no regions showing greater activations for low-energy stimuli when compared to high (Table 4). No other regions defined in this contrast demonstrated significant time of day effects. Areas were labeled following the Talairach Atlas.

#### *Anatomical Region of Interest Analysis*

We compiled a list of regions of interest (ROIs) from previous studies examining the effect of food type on fMRI activation,<sup>9,11,13,14,30</sup> We examined 41 specific ROIs listed in Supplemental Table 1 using segmentations obtained for each individual participant using the FreeSurfer software package. For nearly all areas, high-energy stimuli produced a higher response than low-energy stimuli. Areas and statistical results are reported in a supplemental table.

#### **Discussion**

The results of this study suggest that brain activation is consistently higher in response to high-energy food picture stimuli compared to low-energy pictures for key areas of the brain, regardless of time of day, consistent with our original hypothesis. This agrees with previous research, which has also shown higher activation in similar areas to high-energy stimuli when compared to low-energy stimuli, although a specific aim of the project this was not the primary outcome.<sup>9,13,14</sup>

When examining time of day as the main effect, significant results were seen in six areas: the putamen, lingual gyrus, middle temporal gyrus, middle occipital, parahippocampus/hippocampus, and ventral striatum/amygdala. In each of these areas, there was a reduction in

activation during evening time compared to morning. Although high-energy stimuli still produced a greater activation than low-energy stimuli, these results were contrary to our initial hypothesis that activations would be greater in the evening to both high- and low-energy food. Several of these areas, lingual gyrus, middle temporal gyrus, and middle occipital are part of pathways used for the processing of visual stimuli from the environment. One of the reported areas, the amygdala, is thought to play an important role in the visual evaluation of food stimuli.<sup>31</sup> It is thought to be responsible for evaluating novel stimuli to determine if it may be used as a possible food source.<sup>31</sup>

The two other areas reported above were the hippocampus and ventral striatum which have been implicated, along with the amygdala, as part of dopamine pathways related to motivation and reward.<sup>32</sup> The final reported area of interest is the putamen, which has been shown to be involved specifically in reward history-based action selection.<sup>33</sup> If these highly active reward areas are diminished in the evening, there might similarly be a reduction to other types of stimuli (oral, olfactory). Although our study did not record dopamine levels, recent studies have postulated and shown similar effects in rats when looking at dopamine clearance related to time of day. One study concluded that dopamine systems might be linked to circadian rhythms<sup>34</sup> therefore bringing in to question time of day as an important factor in reward. Our study seems to show a similar effect in dopamine projection areas of the brain (although we did not measure dopamine), but only in regards to visual stimuli. A similar reduction in reward pathways at night to oral stimulus might be a factor to overeating at night; for example, in order for a person to receive the same levels of dopamine activation, they would need to experience higher levels of stimuli. This may mean that they need to see more pictures of food or eat more food, in order to achieve the same level of perceived reward as they would in the morning. This

may seem to be an apparent conflict as we often see the high visual response driving the act to eat. However, our observations seem to indicate that perhaps another neural mechanism is driving the urge to eat at night. Therefore, future studies may want to investigate dopamine levels in response to stimuli and time of day.

In regard to eating habits, it should be understood that brain activation will typically be greater in response to high-energy foods as compared to low-energy foods. Avoiding pictures, advertisements, or actual high-energy food present in the environment is a consideration to brain activation and a driving factor in eating habits. Furthermore, susceptibility to visual stimuli seems to be greater in the morning, so greater care should be placed in the earlier hours of the day. If presented with high calorie stimuli in the morning, for example, being in a coffee shop full of high-calorie breakfast items, one may be more susceptible to these cues and more likely to make a high calorie choice. Understanding this reaction to visual stimuli may have application for weight loss interventions. These data propose interesting questions in the mechanisms driving behavior at different times of the day.

An important clinical aspect for consideration derived from the results of this experiment relates to scan protocol, especially for studies looking at the effects of any type of stimulus. Since the results of this study suggest that time of day can influence the overall response in several key areas of the brain in response to visual stimuli, careful consideration should be given to when participants or groups of participants are scanned or tested. If an entire group of participants are scanned at one particular time, the results may simply be caused by a factor of time.

### *Limitations*

While there are significant strengths in this study, there are also limitations. The population studied was fairly homogenous. All participants were young females and almost all were Caucasian, with the exception of two participants. Furthermore, they were mainly in the normal weight BMI category. Therefore, generalization to a larger population is not possible. Furthermore, the study only looked at acute effects as no intervention was used.

Further research is needed to see if there are similar dampening effects of the reward pathways to other types of stimuli, and if this reduced response may lead to an overconsumption of calories. Further studies taking into account gender, race, cultural eating habits, and age are warranted.

### **Conclusion**

This study adds to the scientific literature showing greater brain response to high-energy foods as compared to low-energy foods and adds that this higher activation to stimuli is true regardless of time of day. Furthermore, our results demonstrate that there is a dampening effect in several important brain areas related to reward and visual processing in the evening as compared to the morning, highlighting the importance that time of day can play a role clinically and perhaps practically in the neural response to visual stimuli. Further study into time effects on stimulus processing in the reward pathways is needed in order to have more conclusive results that have potential application to food-seeking behavior and energy intake.



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**Table 1.** Participant characteristics (n = 15).

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Age (y)	23.33 ± 1.02
Height (cm)	167.91 ± 6.09
Weight (kg)	64.38 ± 7.04
BMI (kg/m <sup>2</sup> )	22.93 ± 2.69
Bod Fat (%)	32.46 ± 5.99

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Values represented are mean ± SD.

BMI = Body Mass Index

**Table 2.** Visual Analog Scales.

	Morning Condition n = 15	Evening Condition n = 15	F	p
How hungry do you feel?	5.29 ± 2.61	6.55 ± 2.65	1.84	0.19
How full do you feel?	1.54 ± 1.45	2.04 ± 2.02	0.47	0.50
How strong is your desire to eat?	4.94 ± 2.56	6.74 ± 3.00	3.36	0.08
How much do you think you could eat now?	5.05 ± 1.82	6.48 ± 2.08	4.83	0.04
What is your urge to eat?	4.45 ± 2.52	6.27 ± 2.86	3.66	0.07
What is your preoccupation with thoughts of food?	3.00 ± 1.90	5.04 ± 3.13	5.51	0.03

Values represented are mean ± SD.

Scale 1–100 mm.

**Table 3.** Regions of interest (ROI) for main effect of time.

ROI Name	No. Voxels	X	Y	Z	Stimulus		
					ME Stimulus	ME Time	× Time Interaction
					F(1, 14)	F(1, 14)	F(1, 14)
L. Putamen	67	29	2	15	2.11	37.17**	1.05
R. Lingual Gyrus	58	-23	62	-4	30.65**	22.46**	.24
R. Middle Temporal Gyrus	45	-41	62	-1	8.41*	33.68**	.02
R. Parahippocampus/Hippocampus	43	-29	23	-13	34.32**	13.12**	.80
R. Middle Occipital	43	-29	83	24	43.30**	21.49**	.14
R. Ventral Striatum/Amygdala	40	-17	2	-7	5.81*	27.49**	.02

All areas reported have greater fMRI activation for high-energy food stimuli than low-energy

food stimuli. (\*p < .05; \*\*p < .001; R. = Right; L. = Left)

ME Stimulus = high energy vs. low energy.

ME Time = morning vs. evening.

ROI = region of interest



**Table 4.** Regions of interest (ROI) for main effect of high energy vs. low energy stimulus.

ROI Name	No. Voxels	X	Y	Z	Stimulus		
					ME Stimulus F(1, 14)	ME Time F(1, 14)	× Time Interaction F(1, 14)
R. Middle Occipital Gyrus	408	-32	83	18	106.86**	1.73	.43
L. Lingual Gyrus	218	8	89	-7	54.07**	.34	1.42
R. Fusiform Gyrus/Parahippocampal Cortex	182	-26	68	-13	6.93**	60.26**	.57
R. Superior Parietal Lobule	150	-23	62	45	79.50**	.84	.44
R. Medial Frontal Gyrus	131	-2	-59	24	56.44**	.08	.58
L. Fusiform Gyrus/Parahippocampal Cortex	97	23	62	-10	55.70**	3.67	.39
L. Medial Frontal Gyrus	76	5	-62	21	114.62**	.02	.03
L. Superior Temporal Gyrus	67	50	56	21	47.44**	.02	1.09
R. Cerebellum	41	-26	77	-25	48.44**	.62	.79

All areas reported have greater fMRI activation for high-energy food stimuli than low-energy food

stimuli. (\* $p < .05$ ; \*\* $p < .001$ ; R = Right; L = Left)

ME Stimulus = high energy vs. low energy.

ME Time = morning vs. evening.

ROI = region of interest

**Table 5.** Supplemental table of masked regions of interest (ROI)

ROI Name	Stimulus		
	ME		× Time
	Stimulus	ME Time	Interaction
	F(1, 14)	F(1, 14)	F(1, 14)
Left Cerebellum White Matter	16.36**	0.03	0.64
Left Cerebellum Cortex	14.32*	0.00	0.02
Left Thalamus Proper	3.17	1.28	1.88
Left Pallidum	1.75	0.15	0.24
Brain Stem	9.61*	1.33	0.93
Left Hippocampus	10.37*	2.69	2.18
Left Amygdala	18.25**	5.71*	0.00
Left Accumbens Area	8.25*	0.14	0.00
Right Cerebellum White Matter	5.61*	0.12	1.26
Right Cerebellum Cortex	8.67*	0.57	0.50
Right Thalamus-Proper	5.34*	3.50	0.63
Right Pallidum	0.04	5.16*	0.13
Right Hippocampus	11.62*	6.51*	0.06
Right Amygdala	9.39*	17.52**	0.03
Right Accumbens Area	3.738	0.00	0.02
CTX Left Caudal Anterior Cingulate	0.019	0.05	0.00
CTX Left Fusiform	14.96*	0.15	1.53
CTX Left Inferior Parietal	6.62*	0.04	1.23
CTX Left Isthmus Cingulate	13.53*	0.00	1.34
CTX Left Lateral Occipital	22.22	0.84	1.59

CTX Left Lingual	7.00*	0.36	0.49
CTX Left Medial Orbitofrontal	4.33	0.00	0.66
CTX Left Middle Temporal	14.23*	0.01	1.57
CTX Left Para Hippocampal	18.77**	0.87	2.05
CTX Left Posterior Cingulate	6.65*	0.02	0.33
CTX Left Rostral Anterior Cingulate	7.40*	0.09	0.29
CTX Left Superior Frontal	6.02*	0.07	0.59
CTX Left Insula	1.67	1.03	0.44
CTX Right Caudal Anterior Cingulate	0.17	0.11	0.01
CTX Right Fusiform	18.05**	2.39	0.01
CTX Right Isthmus Cingulate	8.81*	0.66	1.09
CTX Right Lateral Orbitofrontal	2.05	0.39	2.10
CTX Right Medial Orbitofrontal	13.37*	0.13	0.62
CTX Right Post Central	5.32*	0.13	0.13
CTX Right Posterior Cingulate	4.16	0.36	1.04
CTX Right Precuneus	8.57*	1.30	1.12
CTX Right Rostral Anterior Cingulate	9.78*	0.00	1.41
CTX Right Rostral Middle Frontal	4.47	0.08	0.70
CTX Right Superior Frontal	13.57*	0.38	0.49
CTX Right Superior Temporal	7.90*	0.47	0.00
CTX Right Insula	3.11	2.10	0.16

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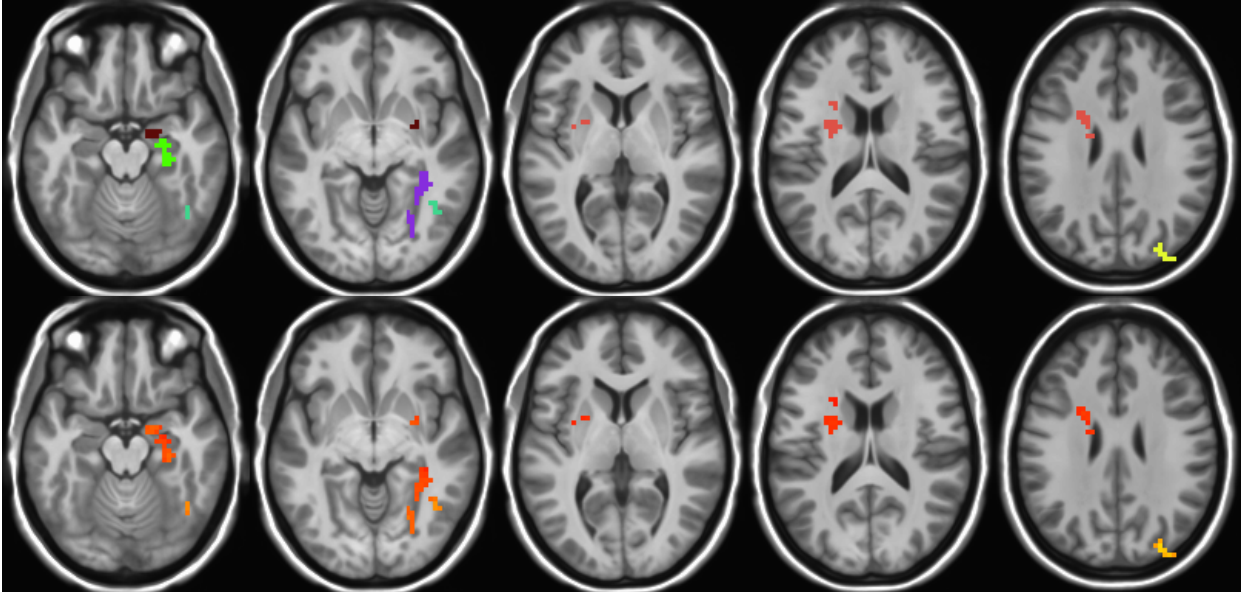
All areas reported have greater fMRI activation for high-energy food stimuli than low-energy food

stimuli. (\* $p < .05$ ; \*\* $p < .001$ ; R = Right; L = Left)

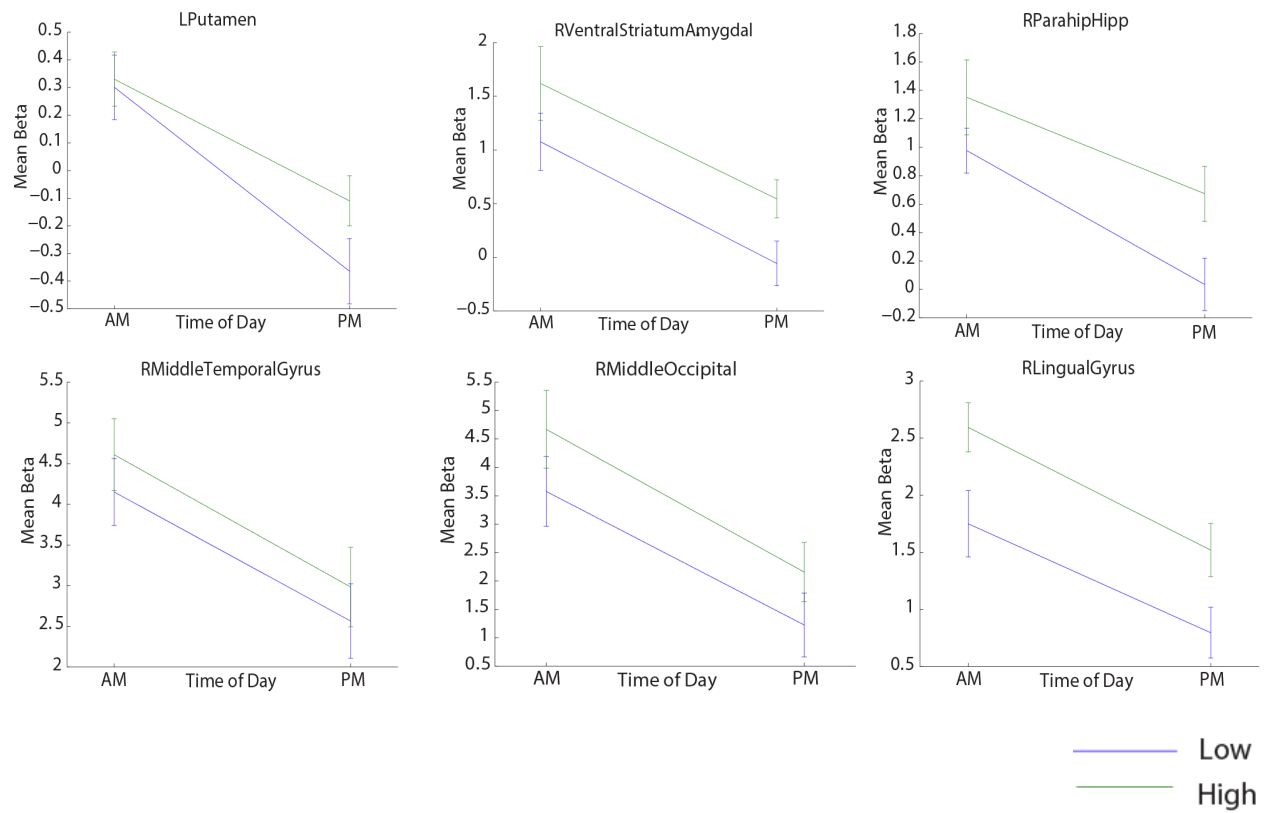
ME Stimulus = high energy vs. low energy.

ME Time = morning vs. evening.

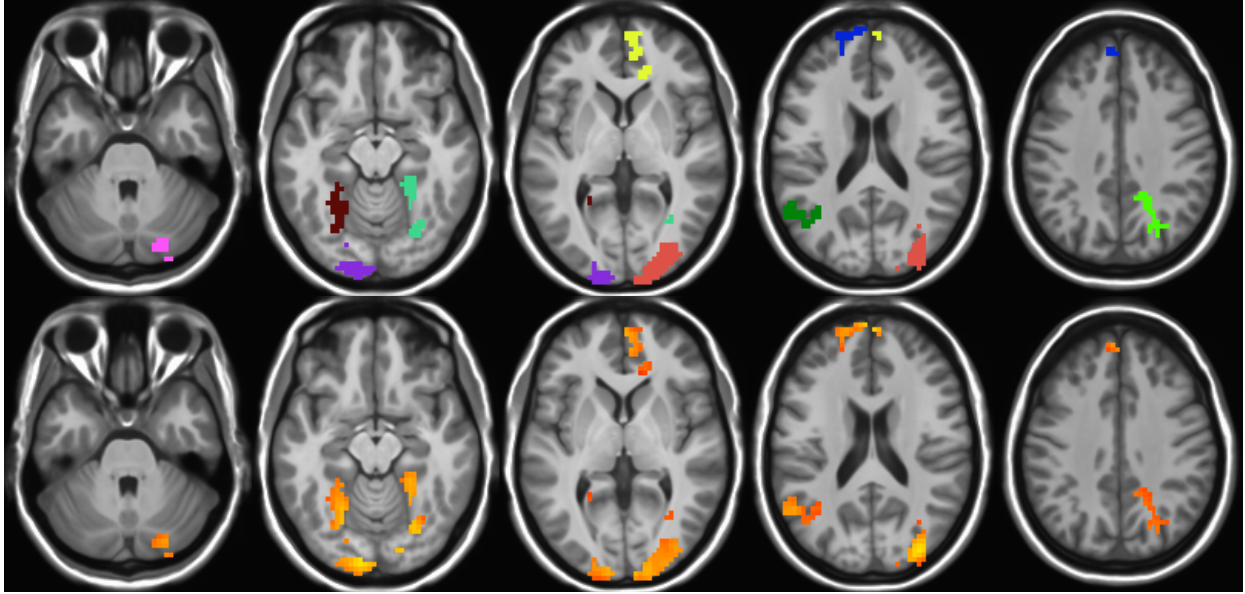
ROI = region of interest



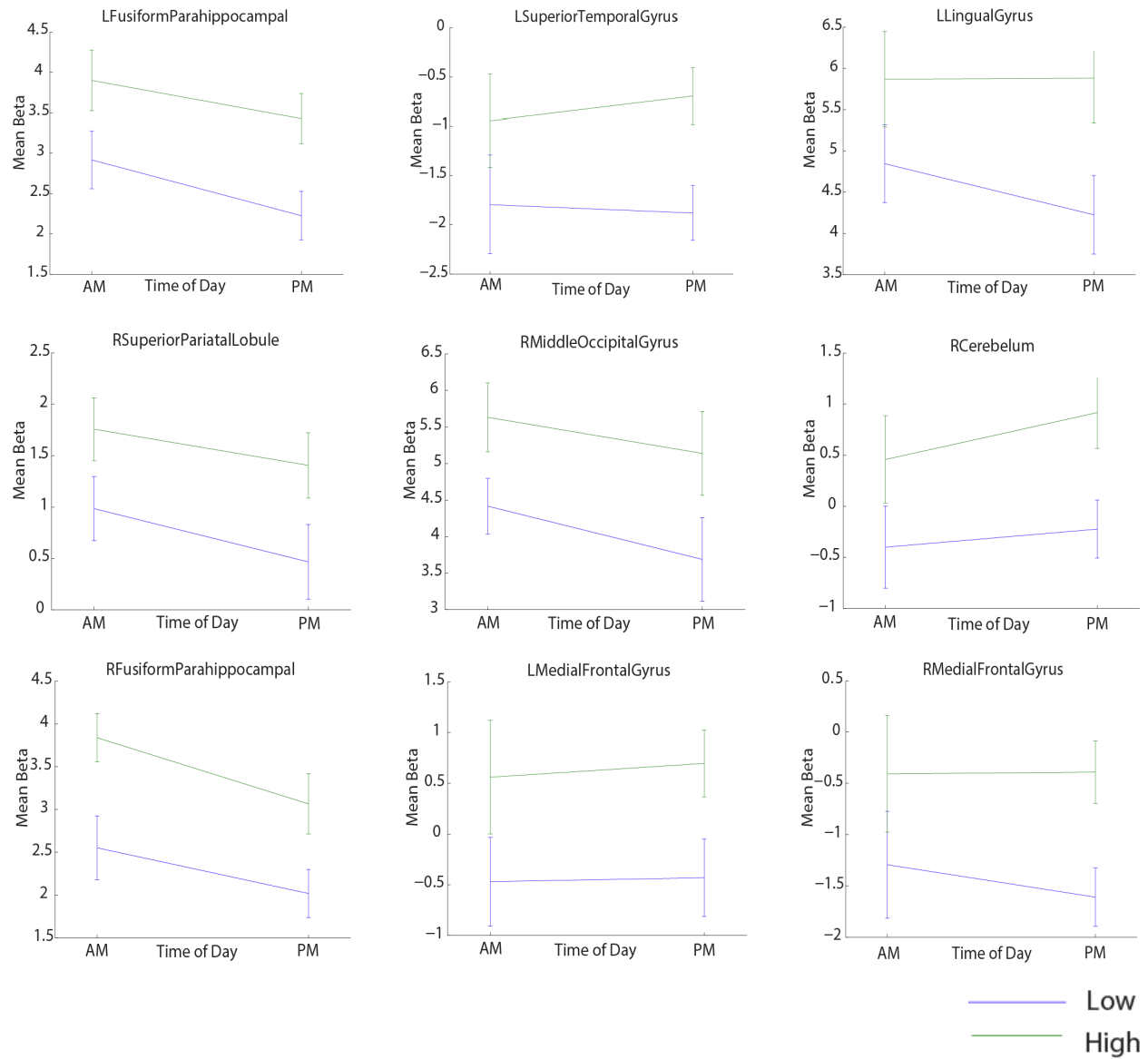
**Figure 1.** Regions of interest for main effect of time.  
Higher intensity is denoted by brighter colors.



**Figure 2.** Mean beta values for activation for main effect of time. All areas depicted are significant for time of day. ( $p \leq .005$ )



**Figure 3.** Regions of interest for main effect of stimulus. Higher intensity is denoted by brighter colors.



**Figure 4.**  
Mean beta values for activation for main effect of stimulus.  
All areas depicted are significant for stimulus type (High Energy/Low Energy) ( $p \leq .005$ )