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Neural Response to Food Cues After Moderate and Vigorous Exercise
in Women: A Randomized Crossover Trial

Jillesa Anderson

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 Response to Food Cues After Moderate and Vigorous Exercise in Women: A Randomized Crossover Trial

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Master of Science

PURPOSE: This study examined the effect of different intensities of acute exercise on attention allocation to visual food cues, postexercise energy intake, and subjective measures of hunger in women. **METHODS:** This crossover study utilized treatment conditions that were randomized and counter-balanced. Fifty-two adult women, 18-29 years, were compared under three separate conditions: no exercise, 45 min of moderate-intensity exercise at 3.9 METs and 22.5 min of vigorous-intensity exercise at 7.8 METs. To measure attention allocation to visual food cues, participants were shown a passive viewing task consisting of a continual stream of pictures of food (high and low calorie) and nonfood stimuli while brain activity was monitored using an EEG. The late positive potential (LPP) component of the scalp-recorded event-related potential (ERP) was used for data analysis. Postexercise food intake was measured during an ad libitum snack offered at the end of each condition. Subjective ratings of appetite were measured before and immediately after each condition using a visual analog scale (VAS). **RESULTS:** No significant differences for LPP were found for the condition (no exercise, moderate exercise or vigorous exercise) by picture type (high calorie, low calorie or nonfood) interaction ($P = 0.184$). Total kcal intake did not differ among the different exercise conditions ($P = 0.19$). However, even though energy intake did not differ among exercise conditions, low-energy-dense foods were consumed at higher rates compared to high-energy-dense foods after the vigorous ($P = 0.0005$) and moderate exercise conditions ($P = 0.02$) compared to the nonexercise condition. Findings from the VAS indicate the moderate exercise session resulted in significantly higher ratings of hunger when compared to the nonexercise ($P = 0.04$) and vigorous exercise sessions ($P = 0.0046$). There was also a significant condition (no exercise, moderate exercise or vigorous exercise) by period (pre- or postexercise) interaction found in postexercise ratings of hunger ($P = 0.018$). The moderate exercise condition reported higher levels of hunger after exercise ($P = 0.0002$). In addition, findings from the VAS also indicated energy for the moderate exercise condition increased postexercise ($P = 0.006$) and was higher than either the nonexercise ($P = 0.011$) or the vigorous exercise conditions ($P = 0.017$). **CONCLUSION:** The results of this study demonstrate that an acute bout of moderate exercise may increase subjective hunger and overall energy without increasing the neural response to visual food cues or postexercise energy intake. Furthermore, it also shows that an acute bout of vigorous exercise did not alter neural response to visual food cues, hunger or energy intake postexercise.

Keywords: neural response to food, event-related potential, food intake, exercise

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Introduction

Adequate food consumption is vital to survival, thus eating is rewarding and reinforced.¹ Sight is important when interacting with the environment to procure food and visual food cues are important moderators of eating behavior.¹⁻⁴ Visual food cues influence the reward centers of the brain and have the potential to alter motivation to consume food.¹ The neural response to visual food cues can also influence appetite as well as nonhomeostatic eating.²⁻⁴

One way of measuring the attention allocation to visual food cues objectively is using electroencephalogram (EEG). EEG is a recording of the brain's intrinsic electric activity from the human scalp.⁵ Electroencephalography materialized as a way to show fluctuations in electrical potentials over time, and it has been used to examine specific cognitive processes.⁵ The electrical activity is known as the electroencephalogram, or EEG.⁶ Over time the EEG has been very useful in both scientific and clinical applications,⁵ and has most recently been used as a way to measure an individual's response to external stimuli, such as visual food cues.⁷

Event-related potentials (ERP) reflect the minuscule changes in the brain's electrical activity as measured from EEG, but time locked to an external stimulus.⁶ ERPs can't be used to definitively localize brain activity.⁶ However, ERPs detect changes over milliseconds, whereas other methods have time resolution between seconds to minutes.⁸ In addition, unlike the functional magnetic resonance imaging (fMRI), ERPs have high temporal resolution that hemodynamic measures lack.⁹

ERPs provide a continuous measure of processing between a stimulus and a response, making it possible to determine which stage or stages of processing are affected by a specific experimental manipulation.⁶ One particular ERP component is the late positive potential (LPP). The LPP occurs between 400-700 ms after stimulus onset.⁷ The LPP is associated with small

brain wave changes provoked by emotional stimuli.¹⁰ Previous studies have shown that LPP amplitudes are higher in food deprived individuals compared to satiated individuals when looking at pictures of food versus pictures of flowers.⁷

The ERPs temporal sensitivity and ability to measure cognitive resources objectively make it an appealing method to further investigate the relationship of exercise and attention allocation to food cues. Using this method of assessment can eliminate the reliance of subjective measures to determine correlates of appetite as well as predictors of energy intake, such as visual food cues.

One moderator of food consumption and appetite is physical activity.^{11,12} Data suggest that alterations in hormones such as ghrelin, insulin, and leptin that occur from physical activity help to explain this phenomenon.¹³ However, very little is known about the effect of physical activity on neural attention allocation to visual food cues.⁷

To our knowledge there has only been one study that has used EEG to evaluate the neural response to food cues after exercising in adults.¹⁴ This study looked at the influence of moderate intensity exercise for 45 min on neural response to food cues using a crossover design. The findings from the study indicate that the LPP was lower toward pictures of food compared to pictures of flowers upon completion of an exercise session.¹⁴

Although these previous data have positive implications for the role of exercise on attention allocation to food cues and weight management, further research in this area is needed. Specifically, to our knowledge, there are no studies that have evaluated how different intensities of activity influence this relationship. Exercise intensity may impact satiety-related hormones and could therefore elicit different physiological and psychological responses.¹⁵ These differing responses may alter the effect of exercise and attention allocation to food cues.

The current environment promotes a sedentary lifestyle and highly-palatable, energy-dense foods are ubiquitous. In addition, marketing techniques using visual food stimuli often advocate unhealthy food choices. Given the amount of exposure to visual food cues in our environment, it seems prudent to investigate things that might alter our sensitivity to these visual cues. Although it has been hypothesized that exercise, both acute and chronic, can effect energy intake, hunger, and attention allocation to food, to date the evidence about this relationship is conflicting, making conclusions about the magnitude and direction difficult.¹⁶⁻¹⁸

The purpose of the current study was to determine the impact of exercise intensity (vigorous and moderate) on postexercise attention allocation to visual food cues using ERP, specifically the LPP component, and on subsequent subjective feelings of hunger and energy intake in women. We hypothesized that attention allocation to visual food cues would decrease following moderate and vigorous exercise compared to no exercise. We hypothesized that subjective ratings of hunger would be higher following moderate and vigorous exercise compared to no exercise. In addition, we hypothesized that food consumption subsequent to vigorous exercise would be lower compared to moderate and no exercise.

Methods

This crossover study utilized treatment conditions that were randomized and counter-balanced. Adult women were compared under three separate conditions: vigorous-intensity exercise, moderate-intensity exercise, and nonexercise. Following each condition the following primary outcomes were evaluated: neural response to visual food cues, postexercise energy intake, and subjective measures of hunger.

Participants

The University's Institutional Review Board (IRB) approved this study and interested participants who were screened and met the inclusion criteria listed below were qualified to participate in the study. Testing started once participants had been approved and written informed consent received.

Fifty-two adult women aged 18-29 years old and native English speakers participated in this study. Only native English speakers were recruited because several measures were available only in English and we did not have the psychometrics or standardization for non-English speakers. All women self-reported to be untrained (vigorous activity no more than three times per week for 20 minutes per session) but able to exercise at a vigorous intensity (walk at 3.8 mile per hour at a grade of 7.5). Participants were also required to perform physical activity without being limited by pain. Participants were excluded from the study for any of the following reasons: orthopedic impairment, current/recent involvement in a vegetarian diet or any other extreme dietary practices, food allergies, chronic/metabolic disease (cardiovascular disease, cancer, diabetes, etc.), previous psychiatric diagnosis, eating disorders, reported alcohol/substance abuse within the past year, the use of tobacco products, pregnant/lactating, current antiepileptic medication use, reported history of learning disability, neurological disorder (traumatic brain injury, seizure disorder, stroke), and/or attention deficit hyperactivity disorder (ADHD).

Experimental Conditions

The testing for this study consisted of three visits to the Brigham Young University Clinical Cognitive Neuroscience and Neuropsychology Lab. Separated by one week, each condition occurred at the same location and same time of day. Furthermore, attention allocation

to visual food cues and subjective measures of hunger for each condition were assessed at approximately the same time of morning, same day of the week, and subsequent to at least seven hours of sleep the previous night. In addition, there was a dietary preload one hour prior to the morning testing, which was the same for each condition. Participants arrived at the lab after voiding, not having consumed caffeine, or performed planned exercise during the previous 24 hours.

Nonexercise Condition

The nonexercise condition acted as a control in which attention allocation to visual food cues was measured. Food consumption and subjective measures of hunger were evaluated in the absence of any planned exercise. Similar to the exercise conditions, participants presented to the lab but rather than exercise, they completed a series of questionnaires.

Moderate-Intensity Exercise Condition

This condition was similar in length to the nonexercise condition except each participant completed a single moderate-intensity exercise bout instead of completing the questionnaire series. During the moderate-intensity exercise bout, participants exercised by walking at 3.8 miles per hour at 0% grade for 45 minutes (3.9 METS).¹⁹ The protocol for the moderate-intensity exercise bout was based off previous research examining the relationship between acute exercise and attention allocation to visual food cues.¹⁴

Vigorous-Intensity Exercise Condition

This condition was similar to the nonexercise condition except that each participant completed a single vigorous-intensity exercise bout instead of completing the questionnaire series. Participants exercised by walking at 3.8 miles per hour at 7.5% grade (7.8 METS)¹⁹ for

22.5 minutes. This speed and grade doubled the intensity compared to the moderate condition but since the duration was half as long, the energy expenditure was equivalent.

Procedures

Visits one through three consisted of participants completing one of the three randomly assigned conditions. Each condition measured the following outcomes: attention allocation to visual food cues, postexercise food intake, and subjective visual analog ratings of hunger.

Before each condition subjects were required to sleep for seven to eight hours the night prior to testing, arrive at the visit adequately hydrated (there were no constraints to participants' water consumption), and consume only the provided amount of breakfast drink one hour prior to arriving at the lab for testing. The breakfast shake provided was a generic breakfast meal replacement drink. The breakfast shake provided contained 10% of the participant's estimated daily energy needs. The estimated daily energy needs for each participant were identified by using the Harris-Benedict equation to predict basal metabolic rate.²⁰ Furthermore, the estimated energy needs were then be multiplied by an activity factor of 1.3²⁰ to maintain consistency with previous research.^{14,20}

Regardless of condition (exercise or nonexercise), subjects completed a visual analog scale questionnaire before the experimental condition and immediately prior to the EEG task that used brain activity to assess attention allocation to visual food cues. Following these conditions, the EEG assessment of visual food cues took place approximately 15 minutes after the exercise period.

In the nonexercise condition, there was no exercise bout and subjects were instructed to complete the questionnaire series upon arrival at the lab. However, consistent with the other conditions, the EEG reading assessing attention allocation to visual food cues and the visual

analog scale questionnaires assessing subjective ratings of hunger remained the same. Under all three conditions, the conducted EEG testing took place between 8:00-10:00 am on the morning of the assigned day. Each computerized task session lasted approximately 30 minutes for initial set up and task duration.

Upon completion of the EEG measurement, subjects engaged in an ad libitum snack consisting of a variety of foods. Participants were allowed to eat as much as they liked but could not take any food out of the lab.

Anthropometry Measurements

Body weight for each participant was measured using a calibrated scale, accurate to the nearest ± 0.1 kilogram. Weight was taken in lightweight work out clothing. Height was measured using a wall-mounted stadiometer accurate to the nearest ± 0.1 centimeter.

Subjective Measures of Hunger

Each participant completed a visual analog scale (VAS) before each experimental condition and immediately prior to each EEG measurement to quantify subjective measures of hunger. A visual analog scale is a questionnaire used for measuring subjective appetite sensations.²¹ This questionnaire can provide further insight into feeding behavior in addition to measures of food intake and objective measures of neural response to visual food cues. Visual analog scales are traditionally composed of lines with words describing extremes fixed on each end.²¹ Subjects are asked to make a mark across the line corresponding with their feelings. Studies report that test/retest reliability results are good in identical or almost identical trials.^{22,23} In addition, visual analog scales have been shown to be a valid method for subjective satiety and hunger measurements.^{22,24} The visual analog scale questionnaire that was used for this study consisted of the following questions: how hungry are you, how thirsty are you, how much

stomach discomfort do you feel, and on average what is your energy level? Responses were reported by marking a line corresponding with their feelings on a line 100 mm long.

Questionnaires

Participants completed a PAR-Q before entering the study to ensure personal safety during physical activity required for completion of the study. During the nonexercise condition, participants were administered a series of questionnaires. In addition, after each EEG task participants were required to complete a Rey Auditory Verbal Learning Test.

PAR-Q: The Physical Activity Readiness Questionnaire is used as a screening tool for anyone who is participating in physical activity. It helps determine the safety or possible risk for individuals who wish to engage in physical activity based on their answers to specific health history questions. It has been found valid and reliable in previous research.²⁵ For the screening purposes of this study, if participants answered yes to any of the seven questions, they were excluded from participating in the study.

Rey Auditory Verbal Learning Test (Rey AVLT): This test evaluates a wide assortment of functions. Among the functions evaluated are short-term auditory-verbal memory, retention of information, as well as differences between learning and retrieval. Participants were read aloud a list of 15 unrelated words. This was repeated over five different trials and each time participants were asked to repeat the words they remembered from the list back to the test administrator. A second list of 15 different unrelated words were then read aloud and the participants were asked to repeat the words they remembered from the second list. At the end of the test, participants were asked to once again repeat the words they remembered from the original list. Studies have shown this test to be both valid and reliable as a psychometric instrument in neuropsychological assessment.²⁶ The Rey AVLT was given to act as a distractor to keep participants in the room

with the food for a standard amount of time. Results from the Rey AVLT were not used for the analysis of this study.

Electroencephalogram

Computerized tasks were used to determine attention allocation to visual food cues by electrical changes in the brain.¹⁰ These tasks lasted approximately 30 minutes. EEG data were recorded from 128 scalp sites using a geodesic sensor net and Electrical Geodesics, Inc., (EGI; Eugene, OR) amplifier system (20K gain, nominal bandpass = .10 - 100Hz). Electrode placements enabled recording of vertical and horizontal eye movements reflecting electro-oculographic (EOG) activity. Data from the EEG were referenced to Cz and digitized continuously at 250Hz with a 16-bit analog-to-digital converter. A right posterior electrode approximately two inches behind the right mastoid process served as common ground. Electrode impedance was maintained below 50k. Electroencephalographic data was segmented off-line and single trial epochs were rejected if voltages exceed 100 μ V, transitional (sample-to-sample) thresholds were greater than 100 μ V, or eye-channel amplitudes were above 70 μ V. Data were digitally rereferenced to an average reference then digitally low-pass filtered at 30Hz.

Experimental Task

Using the ERP data collected from the EEG, attention allocation to visual food cues were tracked and evaluated. For this task participants were shown a continuous stream of visual pictures. During the passive viewing task participants were shown 180 pictures, 60 pictures of high calorie, low calorie, or nonfood stimuli, in random order, each for 2000ms. Stimuli were selected from a food picture database featuring food images with simple figure ground compositions for experimental research.²⁷ Stimuli were classified low calorie if calculated energy

density was ≤ 1.5 .²⁸ Stimuli were classified high calorie if calculated energy density was ≥ 4 .²⁸ Representative pictures of food stimuli used for this study are displayed in Figure 1.

Energy Intake

After each EEG task, postexercise energy intake was measured by snack foods offered ad libitum style throughout the Rey AVLT test that was administered. The protocol and many snacks foods offered for the ad libitum snack were replicated from previous research done by King et al.²⁹ Snack foods offered were diverse in protein, carbohydrates, and fat content to identify macronutrient preferences. Snack foods used for the current study were: apples, carrots, beef jerky, granola bars, chocolate chip cookies, fruit snacks, chips, and M&M's. Participants were instructed to help themselves to as much as they desired until comfortably satisfied. Participants were also notified that more food was available if they wanted. Subjects consumed food in the lab in a relaxing atmosphere with no distractions to minimize any social or environmental influences. The snack foods that were used for this study were each presented to participants in individual bowls. In addition, the bowls were positioned in the same order for all participants to maintain consistency. Food consumption was determined by weighing each bowl before and after consumption. Participants were unaware they were being monitored so that they felt free to consume what they wanted. Energy and macronutrient intake of snack foods consumed was calculated using the manufacturers' nutrition values. Prior to the study, participants completed a food preference questionnaire to ensure acceptability of snack foods that were offered. The food preference questionnaire required participants to rate the snack foods that were offered on a scale from 1 (dislike extremely) to 10 (like extremely). Participants were excluded from the study if they rated 4 or more items 4 or lower on the scale. This ensured that

the snack foods were enticing to the participant. The same snack foods were offered for each condition.

Data Analysis

Sample size for the study was determined a priori. This calculation was based on a previous study that examined the effects of exercise on attention allocation to visual food cues in obese and normal weight women.¹⁴ Based on a standard deviation of $.6\mu\text{V}$, a mean difference in microvolts of $.36\mu\text{V}$ (representing a 20% difference), with an alpha of 0.05 and beta of 0.20, 45 women were needed to complete the study.

Analyses were completed using SAS statistical software (version 9.4; SAS Institute, Inc. Cary, NC). Participant data were reported as means and standard deviations. To evaluate the main and interaction effects of the conditions, a repeated measures analysis of variance (ANOVA) was used. An alpha level of 0.05 was used for this analysis. Post hoc t-tests were performed on significant main effects to identify between-condition differences.

Results

One hundred and seventy-four women were screened for eligibility to participate in the study and 55 met inclusion criteria (Figure 2). Of the 55 women who started the study, 3 dropped out prior to completely finishing and were not included in the data analysis (Figure 2). Reported reasons for drop out were schedule conflicts with time of study (2) and personal injury (1). Additionally, upon analysis of the EEG data, 17 sessions (of 154 total sessions) contained excessive noise or insufficient numbers of trials (i.e., < 8 good trials for each condition)³⁰ and thus insufficient data to include in the data analysis. The 17 “bad” sessions came from 13 unique women and the data from these women were not included in the data analysis of ERP waveforms. Consequently, EEG results were analyzed with only 39 women. However, all 52

women who finished the study were included when analyzing subjective ratings of appetite and postexercise energy intake. Women who were not included in data analysis due to insufficient EEG data did not differ significantly in baseline characteristics compared to those with sufficient EEG data.

The 52 women included in the study were on average 21.4 ± 2.2 years old, weighed 62.4 ± 11.2 kg, and had a BMI of 22.7 ± 3.4 kg m⁻². In addition, 90% of the women were Caucasian, 6% Asian, and 4% American Indian.

There was no significant difference between picture type (high-energy dense, low-energy dense and neutral) and LPP response. There was a significant difference in condition ($P = 0.045$), with vigorous exercise resulting in a higher (i.e., more positive) LLP response than either the moderate or nonexercise condition. However, the condition (no exercise, moderate exercise or vigorous exercise) by picture type (high calorie, low calorie or nonfood) interaction was not significant (Table 1; $P = 0.184$).

Table 2 summarizes the subjective ratings of hunger, thirst, stomach discomfort and energy level before and immediately following each exercise session. There were significant condition (no exercise, moderate exercise or vigorous exercise) by period (pre-exercise vs. postexercise) interactions for hunger ($P = 0.018$), thirst ($P < 0.001$) and energy level ($P = 0.017$) but not for stomach discomfort ($P = 0.175$). Follow-up analyses demonstrated that individuals in the moderate intensity exercise condition reported a significant increase in hunger postexercise compared to pre-exercise ($P = 0.0002$) and this increase was significantly higher than either the nonexercise ($P = 0.003$) or vigorous exercise conditions ($P = 0.0001$). There was no significant change in subjective ratings of hunger from pre-exercise levels following the vigorous exercise condition ($P = 0.994$). In addition, both the moderate ($P = 0.0002$) and vigorous ($P < 0.0001$)

conditions reported greater levels of thirst post exercise when compared to the nonexercise condition. Results indicated a significant increase in thirst postexercise for the vigorous condition when compared to postexercise for the moderate condition ($P < 0.0001$). Finally, energy level for the moderate exercise condition increased after the exercise session ($P = 0.006$) and was higher than either the nonexercise ($P = 0.011$) condition or the vigorous exercise condition ($P = 0.017$). Vigorous exercise did not alter subjective feelings of energy and did not differ from the nonexercise condition ($P = 0.207$).

Table 3 reports the results of the ad libitum snack that was presented at each condition following the EEG measurement. Total kcal intake did not differ among the different exercise conditions ($P = 0.19$). Macronutrient intake of carbohydrate and fat also did not vary statistically by condition ($P > 0.05$). However, there was a small difference in protein intake between the nonexercise and moderate conditions, with the moderate condition consuming more protein ($P = 0.01$). In addition, during the vigorous ($P = 0.001$) and moderate exercise conditions ($P = 0.02$) participants tended to consume more low-energy dense foods (apples and carrots) than the nonexercise condition. There was no difference between conditions in the amount of moderate (fruit snacks and beef jerky; $P = 0.235$) or high-energy dense foods (chips, cookies, granola bars, and M&M's; $P = 0.479$).

Discussion

The purpose of this study was to evaluate the impact of moderate and vigorous exercise on food attention allocation, hunger and subsequent food intake. This study builds off of previous research that has evaluated the impact of moderate intensity exercise on neural response to visual food cues¹⁴ and fills a gap in the current literature related to exercise intensity. The primary finding of our study was that neither moderate nor vigorous intensity exercise altered the

neural response to visual food cues or postexercise energy intake despite the fact that self-reported hunger was higher after moderate intensity exercise.

Measuring attention allocation to visual food cues using event-related potentials after an acute exercise bout is a novel way to measure appetite objectively. To our knowledge, there is only one published study that has used ERP to examine postexercise attention allocation to food cues in adults.¹⁴ This study used moderate intensity exercise (treadmill walking at 3.8 mph and 0% grade) for 45 minutes and was the basis for the exercise prescription used in this study for the moderate intensity condition.¹⁴ Results from this study demonstrated that following a moderate intensity exercise bout there was a reduction in LPP.¹⁴ Surprisingly, the results from our study do not support this finding. We did not see any difference in the LPP ERP component between conditions. One reason for the lack of agreement between our study and the study by Hanlon et al. might be related to the pictures used in each study. Hanlon et al. used pictures of plated meals¹⁴ with no emphasis on high- or low-calorie pictures. We used standardized pictures²⁷ of individual foods (Figure 1) that were high- or low-energy dense. This may have changed the magnitude or variability of the neural response, altering the effect size. While there was no condition-by-picture-type interaction for the LPP ERP component, the mean difference between the moderate exercise and nonexercise conditions was in the expected direction, but the magnitude of the difference was slightly smaller than observed by Hanlon et al.¹⁴ and did not reach significance.

Supplementary to attention allocation to visual food cues, we also measured subjective ratings of hunger using a visual analog scale (VAS). Similar to our findings, research by Maraki et al. found that ratings of hunger increased subsequent to an aerobic exercise class.³¹ However,

like was observed in our study, they also did not observe an increase in energy intake at an ad libitum snack postexercise.³¹

While the findings by Maraki et al. support our results³¹ there are other studies that do not.^{16-18,32,33} These studies have found either no change^{16,32,33} or suppression^{17,18} of subjective hunger postexercise. The cause of these discrepancies in the literature is not completely clear. Design qualities of different studies are likely to explain some of the inconsistency. For example, many of the studies appear to be insufficiently powered, leading to a null finding^{16,17,32}. Additionally, the mode of exercise used may also explain some of the inconsistencies, since the studies that resulted in a null finding or a reduction in subjective hunger used cycling as the mode of exercise.^{16-18,32} Finally, another reason for this might be a result of exercise intensity. In our study, participants reported increased hunger postexercise during moderate exercise but not during vigorous exercise. Since this effect was only observed after moderate exercise, this could imply there may be an intensity threshold after which subjective feelings of hunger decrease. Research by Blundell et al. support this idea.³⁴ They found that the intensity of the exercise matters when evaluating how exercise influences appetite.³⁴ They reported that appetite is suppressed when exercise is $\geq 60\%$ of maximal oxygen uptake.³⁴

Interestingly, while we found an increase in hunger after moderate exercise, no increase in postexercise energy intake was observed. The lack of an observed change in energy intake was true for vigorous exercise as well. This null finding is not unique and is supported by several studies.^{16,31,33} However, there are some findings that have suggested that energy intake is reduced following exercise.^{17,18} The difference in findings could be a result of a number of different design aspects of the various studies, but one that likely plays a role is the timing of the postexercise meal. Studies that show a reduction in energy intake presented food within 15

minutes of the exercise bout,^{17,18} while the studies that saw no change in energy intake presented food at least 40 minutes postexercise.^{16,31,33} Because we presented food after the EEG assessment the participants were given food about 45 minutes postexercise. Thus if there is a suppressive effect of exercise on energy intake it seems to be short lived and does not seem to last beyond 40 minutes postexercise.^{17,18}

Despite no difference in total energy intake postexercise, there was an observed preference towards low-energy-dense foods subsequent to the moderate and vigorous exercise conditions. This preference toward low-energy-dense foods postexercise has been seen in other studies.¹⁸ The drive towards low-energy-dense foods postexercise may at least partially be driven by thirst. Low energy dense foods are higher in water and lower in fat content compared to foods that are classified as moderate- or high-energy dense.³⁵ Not surprisingly, thirst was elevated postexercise and was highest after the vigorous exercise condition. Previous research has demonstrated that a significant increase in thirst is related to an increase in energy from liquid food after 2 hours of cycling at 60% maximum oxygen uptake.¹⁸ Therefore, foods with a higher water content may be preferred following moderate and vigorous exercise.

Few studies have used objective measurement methods to assess attention allocation to visual food cues after exercise. Therefore, using ERP was a unique strength to the study. In addition, the ad libitum snack after each condition gave us another objective approach to assess attention allocation to visual food cues and energy intake. However, there were also some notable limitations to this study. First, participants were recruited generally from a very similar population of healthy women. Consequently, these findings may not apply to a larger, more diverse population. Second, 13 participants were lost as a result of poor EEG data. While this is common when using this measurement method and the rate of loss was similar to other studies, it

is still a threat to the randomization and study design and the results should be interpreted with this limitation in mind. It should be noted that the loss of EEG data seemed to be random and the women who were lost did not differ in baseline characteristics from those women who remained in the study. Additionally, this study focused on acute response to visual food cues after exercise. Attention allocation to visual food cues were measured immediately following each exercise condition (within 45 min). Therefore, these findings do not indicate results of a chronic nature and do not show how long these observed effects on attention allocation to visual food cues last.

Conclusion

The results from this study demonstrate that an acute bout of moderate exercise may increase subjective hunger and overall energy without increasing the neural response towards visual food cues or postexercise energy intake. Furthermore, these results also show for the first time that an acute bout of vigorous exercise did not alter neural response to visual food cues postexercise using low- and high-calorie images. In addition, though there was no observed difference in energy intake, there was an observed increase in preference towards lower energy-dense foods after vigorous and moderate exercise compared to no exercise. Future research evaluating different intensities using relative exercise prescriptions based on VO_2 max and studies that are long term will provide a more complete understanding of the relationship between attention allocation to visual food cues, hunger and postexercise energy intake.

References

1. Mehta S, Melhorn SJ, Smeraglio A, et al. Regional brain response to visual food cues is a marker of satiety that predicts food choice. *The American Journal of Clinical Nutrition*. 2012;96(5):989-999.
2. Cornier M-A, Salzberg AK, Endly DC, Bessesen DH, Rojas DC, Tregellas JR. The effects of overfeeding on the neuronal response to visual food cues in thin and reduced-obese individuals. *Plos One*. 2009;4(7):e6310-e6310.
3. Killgore WDS, Kipman M, Schwab ZJ, et al. Physical exercise and brain responses to images of high-calorie food. *Neuroreport*. 2013;24(17):962-967.
4. Frank S, Laharnar N, Kullmann S, et al. Processing of food pictures: influence of hunger, gender and calorie content. *Brain Research*. 2010;1350:159-166.
5. Borck C. Recording the brain at work: the visible, the readable, and the invisible in electroencephalography. *Journal of the History of the Neurosciences*. 2008;17(3):367-379.
6. Luck SJ. *An introduction to the event-related potential technique*. MIT press; 2014.
7. Stockburger J, Schmälzle R, Fleisch T, Bublatzky F, Schupp HT. The impact of hunger on food cue processing: an event-related brain potential study. *Neuroimage*. 2009;47(4):1819-1829.
8. Anderson JR. *Cognitive psychology and its implications (5th ed.)*. New York, NY, US: Worth Publishers; 2000.
9. Rugg MD, Coles MGH. The ERP and cognitive psychology: conceptual issues. *Electrophysiology of Mind*. Oxford: Oxford University Press; 1996.

10. Hajcak G, MacNamara A, Olvet DM. Event-related potentials, emotion, and emotion regulation: an integrative review. *Developmental Neuropsychology*. 2010;35(2):129-155.
11. Blundell JE, King NA. Physical activity and regulation of food intake: current evidence. *Medicine and Science in Sports and Exercise*. 1999;31(11 Suppl):S573-S583.
12. King NA, Tremblay A, Blundell JE. Effects of exercise on appetite control: implications for energy balance. *Medicine and Science in Sports and Exercise*. 1997;29(8):1076-1089.
13. Borer KT, Wuorinen E, Ku K, Burant C. Appetite responds to changes in meal content, whereas ghrelin, leptin, and insulin track changes in energy availability. *The Journal of Clinical Endocrinology & Metabolism*. 2009;94(7):2290-2298.
14. Hanlon B, Larson MJ, Bailey BW, LeCheminant JD. Neural response to pictures of food after exercise in normal-weight and obese women. *Medicine and Science in Sports and Exercise*. 2012;44(10):1864-1870.
15. Martins C, Morgan L, Truby H. A review of the effects of exercise on appetite regulation: an obesity perspective. *International Journal of Obesity*. 2008;32(9):1337-1347.
16. Hagobian TA, Yamashiro M, Hinkel-Lipsker J, Streder K, Evero N, Hackney T. Effects of acute exercise on appetite hormones and ad libitum energy intake in men and women. *Applied Physiology, Nutrition, and Metabolism = Physiologie Appliquée, Nutrition Et Métabolisme*. 2013;38(1):66-72.
17. Kissileff HR, Pi-Sunyer FX, Segal K, Meltzer S, Foelsch PA. Acute effects of exercise on food intake in obese and nonobese women. *The American Journal of Clinical Nutrition*. 1990;52(2):240-245.

18. Westerterp-Plantenga MS, Verwegen CR, Ijedaema MJ, Wijckmans NE, Saris WH. Acute effects of exercise or sauna on appetite in obese and nonobese men. *Physiology & Behavior*. 1997;62(6):1345-1354.
19. Glass S. GB. *ACSM's Metabolic Calculation Handbook*. Baltimore: Lippincott Williams & Wilkins; 2007.
20. University CM. Basal Energy Expenditure: Harris-Benedict Equation. 2000; <http://www-users.med.cornell.edu/~spon/picu/calc/beecalc.htm>.
21. Flint A, Raben A, Blundell JE, Astrup A. Reproducibility, power and validity of visual analogue scales in assessment of appetite sensations in single test meal studies. *International Journal of Obesity and Related Metabolic Disorders: Journal of The International Association for the Study of Obesity*. 2000;24(1):38-48.
22. Porrini M, Crovetti R, Testolin G, Silva S. Evaluation of satiety sensations and food intake after different preloads. *Appetite*. 1995;25(1):17-30.
23. Lappalainen R, Mennen L, van Weert L, Mykkänen H. Drinking water with a meal: a simple method of coping with feelings of hunger, satiety and desire to eat. *European Journal of Clinical Nutrition*. 1993;47(11):815-819.
24. Parker BA, Sturm K, MacIntosh CG, Feinle C, Horowitz M, Chapman IM. Relation between food intake and visual analogue scale ratings of appetite and other sensations in healthy older and young subjects. *European Journal of Clinical Nutrition*. 2004;58(2):212-218.
25. Whaley M. H BPH, Otto R.M. *ACSM's Guidelines for Exercise Testing and Prescription: 9th Edition*. Baltimore, Maryland: Lippincott Williams & Wilkins; 2013.

26. de Sousa Magalhães S, Malloy-Diniz LF, Hamdan AC. Validity convergent and reliability test-retest of the Rey Auditory Verbal Learning Test. *Clinical Neuropsychiatry: Journal of Treatment Evaluation*. 2012;9(3):129-137.
27. Blechert J, Meule A, Busch NA, Ohla K. Food-pics: an image database for experimental research on eating and appetite. *Frontiers in Psychology*. 2014;5:617-617.
28. Rolls B. *The Volumetrics Eating Plan: Techniques and Recipes for Feeling Full on Fewer Calories*. New York City, New York: HarperCollins Publishers; 2007.
29. King JA, Wasse LK, Broom DR, Stensel DJ. Influence of brisk walking on appetite, energy intake, and plasma acylated ghrelin. *Medicine and Science in Sports and Exercise*. 2010;42(3):485-492.
30. Moran TP, Jendrusina AA, Moser JS. The psychometric properties of the late positive potential during emotion processing and regulation. *Brain Research*. 2013;1516:66-75.
31. Maraki M, Tsofliou F, Pitsiladis YP, Malkova D, Mutrie N, Higgins S. Acute effects of a single exercise class on appetite, energy intake and mood. Is there a time of day effect? *Appetite*. 2005;45(3):272-278.
32. Thivel D, Metz L, Aucouturier J, Brakonietcki K, Duche P, Morio B. The effects of imposed sedentary behavior and exercise on energy intake in adolescents with obesity. *Journal of Developmental and Behavioral Pediatrics: JDBP*. 2013;34(8):616-622.
33. Deighton K, Karra E, Batterham RL, Stensel DJ. Appetite, energy intake, and PYY3-36 responses to energy-matched continuous exercise and submaximal high-intensity exercise. *Applied Physiology, Nutrition, and Metabolism = Physiologie Appliquée, Nutrition Et Métabolisme*. 2013;38(9):947-952.

34. Blundell JE, Stubbs RJ, Hughes DA, Whybrow S, King NA. Cross talk between physical activity and appetite control: does physical activity stimulate appetite? *The Proceedings of the Nutrition Society*. 2003;62(3):651-661.
35. Promotion NCfCDPaH. Low-Energy-Dense Foods and Weight Management: Cutting Calories While Controlling Hunger. Vol 5: Department of Health and Human Services:1-7.

Table 1. Event-related potentials by exercise and picture condition (n = 39)

	Nonexercise	Moderate exercise	Vigorous exercise	F	P
LPP high calorie (μV)	1.32 \pm 1.48	1.19 \pm 2.18	2.41 \pm 3.98	1.56	0.184
LPP low calorie (μV)	1.43 \pm 1.68	1.24 \pm 2.25	1.78 \pm 2.12		
LPP nonfood (μV)	1.44 \pm 1.78	1.91 \pm 1.43	1.64 \pm 2.7		
Trials high calorie	49.53 \pm 12.44	48.0 \pm 13.26	44.69 \pm 14.25	0.30	0.875
Trials low calorie	48.97 \pm 12.7	48.49 \pm 13.04	43.36 \pm 14.72		
Trials nonfood	47.0 \pm 13.84	47.1 \pm 14.61	44.39 \pm 13.11		

LPP = Late positive potential

Values represented are mean \pm SD.

F and P-values refer to the picture by condition interaction.

Table 2. Pre- and postexercise subjective ratings of hunger, thirst, stomach discomfort and energy levels assessed using a visual analog scale (n = 52)

Variable	Nonexercise	Moderate		Vigorous		F	P
		Pre-exercise	Postexercise	Pre-exercise	Postexercise		
Hunger (mm)	24.4 ± 19.7 ^a	24.0 ± 20.0 ^a	35.2 ± 26.3 ^b	23.8 ± 18.6 ^a	23.8 ± 20.9 ^a	4.04	0.019
Thirst (mm)	40.0 ± 18.9 ^a	39.3 ± 19.7 ^a	53.4 ± 20.4 ^b	37.1 ± 18.2 ^a	66.2 ± 21.9 ^c	18.6	<0.001
Stomach Discomfort (mm)	13.2 ± 20.7	15.3 ± 20.5	15.7 ± 22.2	13.5 ± 18	18.9 ± 21.1	1.75	0.175
Energy Levels (mm)	48.7 ± 18.5 ^a	48.5 ± 17.4 ^a	55.5 ± 15.4 ^b	52.1 ± 18.3 ^{a,b}	49.9 ± 20.3 ^a	4.14	0.017

Values represented are mean ± SD.

F and P = Condition*period interaction.

^{a,b,c} = Same letter signifies no significant difference between group means.

Table 3. Results from postintervention ad libitum snack (n = 52)

	Nonexercise	Moderate exercise	Vigorous exercise	F	P
Energy Intake (kcal)	324.8 ± 206.3	363.1 ± 235.0	355.7 ± 223.9	1.72	0.185
CHO (g)	50.7 ± 31.5	57.0 ± 40.3	56.6 ± 36.7	1.86	0.161
Protein (g)	9.0 ± 7.4 ^a	10.7 ± 7.8 ^b	10.4 ± 7.7 ^{a,b}	3.29	0.041
Fat (g)	9.7 ± 8.2	10.4 ± 8.8	9.7 ± 8.0	0.66	0.520
Low ED (g)	56.6 ± 48.6 ^a	72.1 ± 53.5 ^b	80.3 ± 50.6 ^b	6.73	0.002
Med ED (g)	29.3 ± 30.6	33.5 ± 34.3	33.7 ± 41.2	1.47	0.235
High ED (g)	42.9 ± 37.9	47.2 ± 44.7	44.3 ± 36.8	0.74	0.479

Values represented are mean ± SD.

ED = Energy density

^{a,b} = Same letter signifies no significant difference by condition.

High calorie



Low calorie



Nonfood



Figure 1. Representative examples of the food and nonfood stimuli

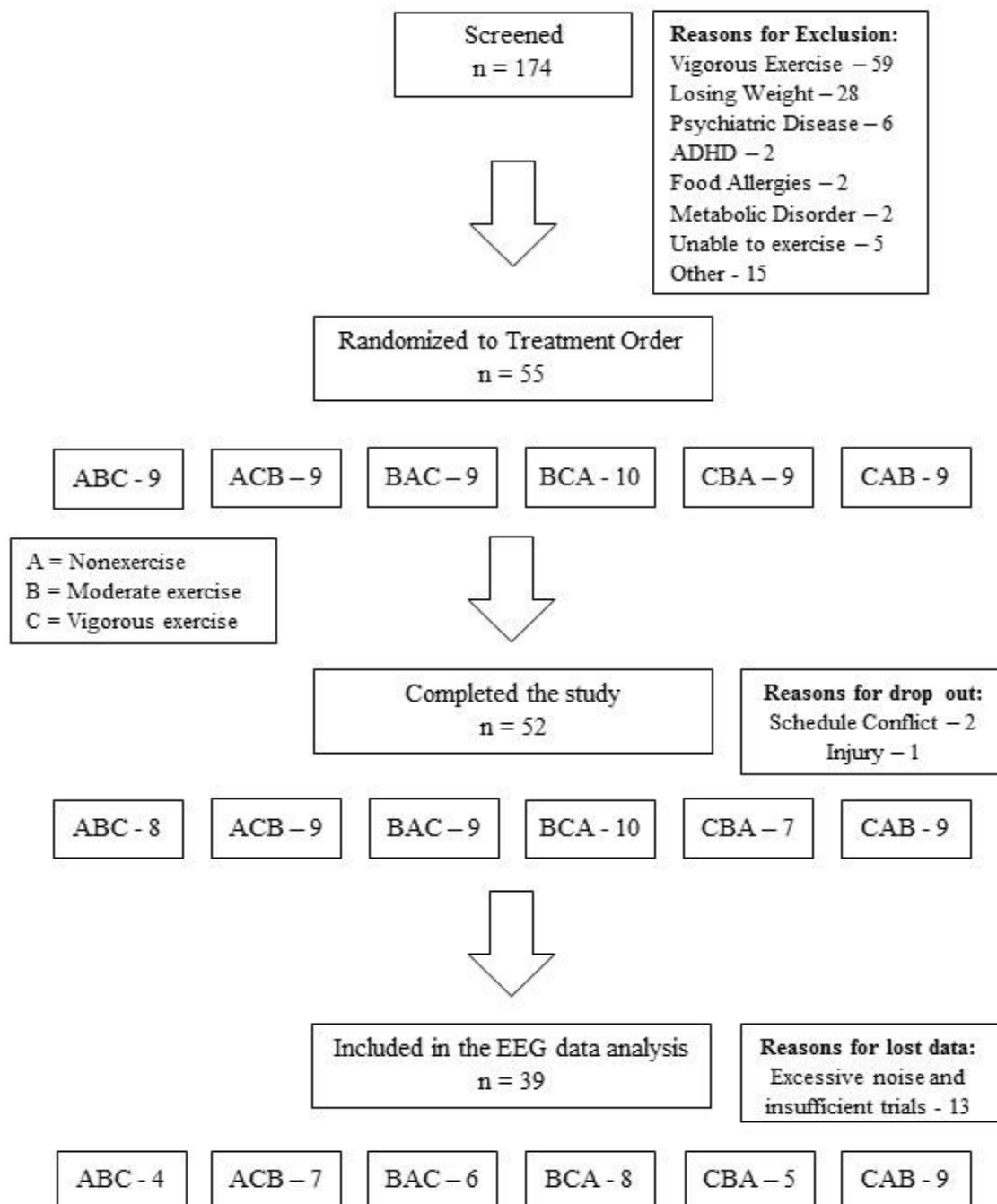


Figure 2: Consort Diagram