

Published: June 30, 2023

Citation: Wheeler NB, Colella JA, et al., 2023. Late-stage Attentional Bias towards Food Cues Varies According to Weight Status, Medical Research Archives, [online] 11(6).

<https://doi.org/10.18103/mra.v11i6.3918>

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DOI

<https://doi.org/10.18103/mra.v11i6.3918>

ISSN: 2375-1924

RESEARCH ARTICLE

Late-stage Attentional Bias towards Food Cues Varies According to Weight Status

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ABSTRACT

The Current food environment has become increasingly obesogenic, with rates of obesity and related conditions continually rising. Advertisements for energy-dense foods are abundant and promote unhealthy eating behaviors by capitalizing on one's attentional bias towards food cues, a cognitive process resulting from the sensitization of highly reinforcing food. A heightened awareness towards food cues may promote overconsumption of energy-dense foods. The current study employed novel eye-tracking methodology to capture sustained, or late-stage, attentional bias towards food cues. Late-stage attentional bias is the aspect of attentional bias under conscious control and likely more prone to modification compared to initial/ early-stage attentional bias, which reflects automatic processes. The present study hypothesized late-stage attentional bias towards food cues is greater among individuals classified as overweight/obese than those classified as normal weight. Thirty (30) participants classified as overweight/obese (BMI ≥ 25) and 47 classified as normal weight (BMI < 25) were assessed for late-stage attentional bias towards food cues, conceptualized as the percentage of time fixated on food cues when both food and neutral images were presented during a food-specific visual probe procedure task. Percentage of time fixated on food cues was 51.25 ± 1.27 (mean \pm SE) among individuals classified as overweight to obese while those classified as normal weight had a percent fixation of 47.26 ± 0.87 ($P=0.03$). In conclusion, individuals classified as overweight to obese have greater late-stage attentional bias towards food cues. This establishes an important factor influencing energy intake that may be modified in future clinical trials.

Keywords: Attentional Bias; Obesity; Environmental Salience; Food Reinforcement; Visual Probe Procedure; Fixation time

I. Introduction

Obesity prevalence in the United States has steadily risen from 8% in the early 1980s to 22% by 2005¹. Today, over 70% of the American population is classified as overweight or obese^{2,3}. Understanding contributing factors to this endemic could be essential for reversing these trends and improving the health of many.

Overconsumption of energy dense foods is a main contributing factor in the rising number of individuals classified as overweight to obese^{1,4,5}. Inherent biases individuals have related to sensory or emotional feelings towards these foods is known to play a role in such overconsumption⁶. Food advertisements commonly found throughout popular media target these sensory and emotional feelings, promoting an environmental salience towards these foods, increasing their attractiveness⁷. Energy-dense, palatable foods are the most abundantly advertised foods, especially those targeting children and adolescents^{8,9}. These advertisements have been linked to the overconsumption of energy dense, nutrient poor food and unhealthy BMI¹⁰⁻¹². These correlations can be explained by the heightened responsiveness to environmental food cues individuals classified as overweight to obese can display, an area that has been under study as early as the 1970's with Rodin and Slochower's seminal work^{13,14}. The term "attentional bias" has since been coined to convey this heightened responsiveness, specifically referring to a heightened attention toward a particular stimulus. Attentional bias towards addictive stimuli are well documented¹⁵⁻¹⁸ supporting the incentive-sensitization hypothesis, which posits rewarding stimuli capture attention and induce cravings¹⁹. Following up on Rodin and Slochower's initial work, attentional bias research has extended to eating behaviors, employing behavioral tasks such as a food-specific Stroop test or Dot-Probe tasks to measure reaction time and accuracy in identifying colors of food and neutral words. For these tasks, reaction time and accuracy become surrogate measures for attentional bias. Indeed, several trials have demonstrated a link between weight status and these measures of attentional bias, whereas individuals classified as overweight or obese have greater attentional bias towards food cues than normal weight controls²⁰⁻²³.

More recently, eye-tracking technology has come to the forefront of attentional bias research, allowing for the noninvasive assessment of eye movements as individuals examine visual stimuli. Eye movements are directly observable and an ecologically valid measurement of the visual attention process, measuring the tendency to automatically devote attention to specific stimuli

^{24,25}. This data provides detailed information into how individuals respond to visual stimuli in real time. Unlike the aforementioned behavioral indices of attentional bias (reaction time, accuracy), eye tracking provides a direct measure of attentional processing and can differentiate between early and late stages of attentional processing. The direction of an initial fixation is thought to assess automatic processes related to the initial salience of the visual stimuli whereas total fixation time (time spent looking at one visual stimuli over another) is considered to assess late stages of attentional processing that are under coconscious control²⁶. Many of these studies have utilized a visual dot-probe task in conjunction with eye tracking, where two images are presented on a computer screen (one food and one non food/neutral) for a certain amount of time before a probe appears in place of one of the images. Participants are required to respond to the probe by selecting the corresponding computer key as quickly as they can indicating if the probe appears on the right or left side of the screen. In this way, both visual eye tracking data (assessed when looking at images before probe appears) and reaction time (time to react to probe) can be assessed as measures of attentional bias^{25,27-29}. These studies all report differences in attentional bias between individuals classified as overweight to obese when compared to normal weight controls, although the parameters and exact indices seem to vary. Specifically, Werthmann et al. demonstrated only initial fixation direction and the time spent in that initial fixation differed between groups, indicating automatic processing is primarily different between weight status group²⁵. Both Nijs et al. and Castellanos et al. additionally assessed the effects of fed and fasted states on attentional bias between weight status groups. Nijs et al. demonstrated no difference between groups or fed/fasted conditions in eye tracking data, whereas all participants demonstrated a greater attentional bias towards food. Interestingly, when looking at reaction time, this study demonstrated normal-weight individuals responded faster to the visual probe than the overweight/obese group²⁹. Castellanos et al. demonstrated all participants had an elevated attentional bias while fasted, while only the overweight/obese group demonstrated greater attentional bias towards food cues in the fed condition. In contrast to Werthmann et al., these results applied to both initial fixation direction and total fixation time²⁸. Graham et al. took a different twist, assessing the interaction between different types of food (low energy, high-energy sweet, high-energy savory) and weight status. Interestingly, total fixation time did not differ

between groups, while initial fixation direction was greater towards low-energy foods in the overweight/obese group compared to control²⁷.

Employing these adjustments to the Dot-Probe task with eye tracking, the current study sought to demonstrate differences in attentional bias towards food cues (specifically late-stage attentional bias, conceptualized as percent fixating time) between individuals classified as overweight to obese (BMI ≥ 25) and those who are classified as normal weight (BMI < 25). We hypothesized individuals classified as overweight or obese would spend a greater percentage of time fixated on food cues than those classified as normal weight, indicating they have greater late-stage attentional processing, which is under coconscious control, as opposed to initial fixation direction that is automatic²⁵.

II. Methods

2.1 Participants

Participants classified as normal weight, BMI < 25 (N=47, 24 female) and those classified as overweight to obese, BMI ≥ 25 (N=30, 14 female) were recruited using flyers and email advertisements. Recruitment occurred between April and November 2021 and was approved by the University of Kentucky IRB (protocol # 69120). Participants could not be tobacco users, pregnant, or nursing. Individuals were also required to be at least 18 years old. The sample of participants classified as overweight to obese were recruited from a separate study that included baseline assessments for attentional bias and body composition³⁰. The inclusion/exclusion criteria remained the same for both studies, except for weight status, with only healthy individuals absent of any chronic condition (diabetes, heart disease, cancer) included.

2.2 Measures

2.2.1 Height and Weight

Height was measured in triplicate to the nearest 0.1 cm using a stadiometer (Seca; Chino, CA). Body weight was measured using a calibrated digital scale connected to the BodPod (Cosmed, USA) to the nearest 0.01 kg. Measures were completed with participants wearing spandex shorts and sports bra (females) or no shirt (males) as required for the BodPod assessment (below). BMI was calculated during the screening and enrollment visit to ensure participants qualified for the study.

2.2.2 Body Composition

Kg of body fat and fat-free mass were determined via air displacement plethysmography (BodPod, Cosmed USA) and percent body fat

calculated. Participants were assessed prior to completing the attentional bias task and were at least 3 hours post-prandial. The BodPod is a reliable and valid assessment tool for body composition in adults, offering a quick and non-invasive assessment of body composition³¹. The Siri or Schutte density model was used, depending on race, to convert body density to percent body fat^{32,33}. Thoracic gas volume was measured according to manufacturer's recommendations.

2.2.3 Attentional Bias

The current study employed similar eye-tracking procedures as previous studies noted with a few important adjustments. First, we utilized a 3,000ms presentation time for the pictures of food cues (before being replaced by the visual probe). Of the prior studies mentioned, Castellanos et al.'s 2,000 ms presentation time was the longest, while others typically use 500 or 1,000ms, following prior eye-tracking addiction research that traditionally utilizes a 1,000ms presentation time¹⁵⁻¹⁸. The issue, we believe, in borrowing from addictive research in this scenario, is that food is much less reinforcing to most people compared to the reinforcing value of drugs of abuse among those with an addictive disorder^{34,35}. Therefore, individuals with an addictive disorder will be much more sensitive towards drug-related stimuli than a healthy individual is towards food. Prior to our eye tracking studies, we piloted this task and observed great variability among 5 test subjects using the 1,000ms presentation time (within subject SD range 0-50.1) and for the 2,000ms presentation time (SD range 11.5 to 43.9). The 3,000ms presentation time yielded a within-subject SD range of 14.9 to 21.8 and therefore was chosen for this study. We believe this may be the reason some of these prior studies did not observe a difference between groups or conditions in total fixation time. We also improved upon prior studies by developing a novel metric to assess total fixation time, or late-stage attentional bias. This new metric, mean percentage of time fixated on food cues, or *percent fixation time*, is calculated by dividing the fixation time for the food cue by the fixation time for the food + neutral cue. This is done for each individual trial and then averaged across the entire test, providing an average % fixation time. This is an improvement over the traditional total fixation time as some trials may result in 0ms of fixation time for either image (in the event a participant blinks or looks away and their eyes were not recaptured quick enough). If a participant has even one of these trials, their total fixation time may look greatly reduced compared to a participant who did not have any such trials. By expressing fixation time as a percentage (and

removing the trials that did not register any fixation time) we avoid this potential issue. Lastly, the current study assessed individuals who were neither satiated nor fasted, assessing every participant in the afternoon between lunch and dinner who reported to be only moderately hungry. This may represent a more typical, real-world scenario, where someone is not extremely hungry nor extremely full.

Attentional bias was assessed by the visual probe procedure adapted for food cues³⁶⁻³⁸. Ten images of energy dense foods (critical task stimuli) were paired with ten images of non-food (neutral) stimuli that included nature images, furniture, and buildings. Other pairs included two neutral (non-food) images used as filler trials. All image pairs were matched for color and complexity, had dimensions of 680x491 pixels with a 96 dpi. Pairs were presented one at a time in random order. Image pairs were shown for a total of 3,000ms after which a yellow dot appeared in place of one of the images. Participants were instructed to right click the computer mouse if the yellow dot appeared on the right side of the screen and left click if the yellow circle appeared on the left of the screen. Participants were positioned so that their eyes were 65-75cm away from the screen. Calibrations were performed to ensure that the participants' eyes were being tracked properly before each trial. Each pair of images (both those containing food images and those not) were shown twice. The orientation of the images were flipped so neither food nor neutral image was shown on the same side of the screen twice. There was a total of 80 trials (pairs) shown to each participant. Half (40) of the trials contained food cues and the other 40 pairs contained only non-food, filler, trials. The primary outcome was time in ms fixated on food and neutral images, which was used to calculate the percentage of time fixated on food cues as: $\text{ms fixated on food cues} / (\text{ms fixated on food cues} + \text{ms fixated on neutral cues})$.

2.2.4 Hunger and Satiety

Hunger and Satiety was assessed prior to the attentional bias assessment via visual analog scales (VAS) where participants dragged a slider on a computer to indicate how hungry they were on a scale of 0 "not hungry at all" to 100 "extremely hungry." Participants were scheduled for their assessment visit between lunch and dinner and instructed to attend the experimental session 3-5 hours post prandial. This was designed so participants were neither hungry or satiated, thus assessing attentional bias under neutral conditions.

2.3 Statistical analysis

Repeated measures analysis of variance (ANOVA) was used to assess differences in attentional bias and demographic variables between groups (obese/overweight vs normal weight). A linear regression model using attentional bias as the dependent variable was constructed using body fat percentage and age as predictor variables. In the planned repeated measures ANOVA a sample of 30 participants has 80% power to detect an interaction which is 0.37 times the standard deviation between participants provided the correlation within participants is 0.5 or larger (effect size 0.517). Thus, our sample size of 30 and 47 participants for each group was adequate.

III. Results

The group classified as obese/overweight was younger, had a greater BMI, and a greater body fat percentage when compared to the normal weight group (Table 1). To test if these differences influenced attentional bias for food cues, a linear regression model was constructed to determine predictors of attentional bias. This model demonstrated age was not a significant predictor of attentional bias ($P=0.30$) while BMI and body fat were a significant predictors ($P<0.05$).

Table 1. Participant characteristics. Data presented as means \pm SD.

	Overweight (n=30)	Normal Weight (n=47)
Age (years)*	31.8 \pm 8.53	39.9 \pm 16.05
BMI (kg/m ²)*	32.7 \pm 5.20	22.6 \pm 1.65
% body fat*	38.8 \pm 8.08	21.6 \pm 7.36

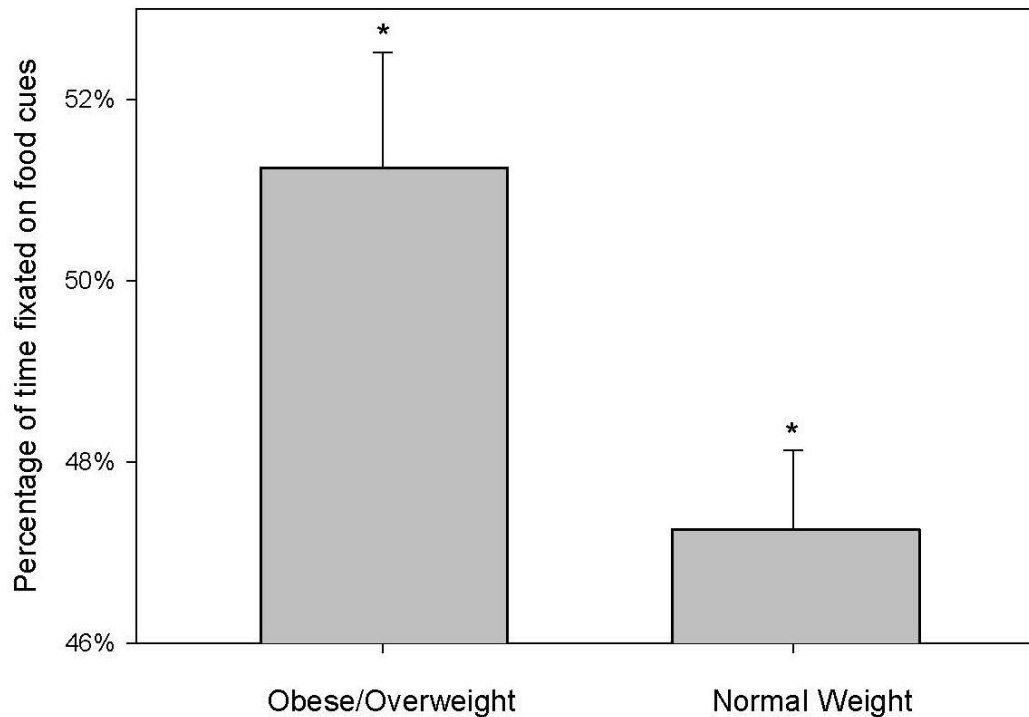
*indicates significant difference between groups ($P\leq 0.05$)

BMI = Body Mass Index

As depicted in Figure 1, there was a significant difference ($P = 0.03$) in percent fixation time between groups. Percent fixation time on food was 51.25 ± 1.27 among individuals classified as overweight to obese while those classified as normal weight had a percent fixation of 47.26 ± 0.87 (mean \pm SE).

As expected, hunger was not correlated with attentional bias scores ($r=0.13$, $P>0.2$). This is likely due to participants were neither very hungry or very satiated when assessed, mean \pm SE hunger score: 41.5 ± 5.6 .

Figure 1: percentage of time fixated on food cues during the food-specific Dot-Probe task significantly is significantly greater among participants classified as overweight to obese ($BMI \geq 25$) than those of normal ($BMI < 25$).



*Significantly different between conditions, $P=0.03$

IV. Discussion

In line with our hypothesis, the current study demonstrated individuals classified as overweight to obese have a greater late-stage attentional bias towards food cues than their normal-weight counterparts. Although a cause and effect relationship cannot be determined from the present cross-sectional study, others have linked greater energy intakes to greater attentional bias for food cues and food reinforcement³⁹⁻⁴³ while others have linked greater attentional bias towards food cues to future weight gain⁴⁴. This supports the notion obesity is not creating an attentional bias towards food cues, rather, obesity is the result of an attentional bias-mediated increase in energy intake^{25,41,42}.

Unlike prior studies addressing this question, attentional bias was conceptualized as the average percentage of time fixated on food cues after a 3,000ms presentation time, indicative of

greater attentional processing that is under coconscious control. We chose not to focus on initial fixation direction as 1) this has been studied before and is not influenced by the novel aspects of the present study (3,000ms presentation time, % fixation time calculation) and 2) this automatic process is likely not modifiable in future training interventions.

When considering the research on attentional bias towards food cues and its relationship with eating behaviors and weight status as a whole, it is difficult to arrive at a single conclusion due to the various methodology. A review of attentional bias literature by Hendrikse et al. recognized this wide-range of methodology in conceptualizing attentional bias, such as total fixation duration towards food cues, the order of fixation (initial, latent) or the reaction time to a dot probe^{20,41,42,45}. Despite the inconsistency of assessment techniques, this review concluded that

there is sufficient evidence demonstrating attentional bias towards food cues is increased among individuals classified as overweight to obese⁴².

Conversely, a recent review concluded that individuals classified as overweight or obese did not differ when compared to normal weight controls in their fixation-direction or fixation-duration bias⁴⁶. Participant characteristics such as the physiological state assessed (fasted vs. satiated), age, sex, or other pre-existing conditions may have all contributed to variability between studies to cause difficulties in identifying differences. The 3,000ms presentation time of the current trial, conceptualizing attentional bias as mean percent fixation time, and assessing individuals who were neither extremely hungry or satiated are all potential reasons we were able to identify differences in attentional bias, specifically late-stage, in our groups of normal weight vs. those classified as overweight to obese.

A possible underlying physiological response for the increased attentional bias with obesity lies in a modification of central neuronal pathways⁴⁷. This is well documented in the drug abuse literature, where repeated exposure to the stimuli promotes a sense of wanting and an unavoidable craving⁴⁸. Food cravings, much like drug abuse, increases the neural activity of the corticostriatal regions of the brain (motivation-reward regions) and is more pronounced among individuals classified as obese⁴⁹. This is also supported in studies identifying a genetic component to food cue reactivity that share similarities with drug abuse⁵⁰⁻⁵³. As noted, this is likely a prime cause of over consumption and obesity, but also may pose as a barrier to weight loss as these individuals are more affected by food cues than their normal-weight counterparts. This scenario, where some individuals are more susceptible to food's reinforcing effects due to certain genetic components of their dopamine reward system, is difficult to manage as exposure to the reinforcer (food in this case) is necessary for survival. This is an area where attentional bias training interventions could play a major role, aiding those individuals who are highly sensitive to food cues to either prevent weight gain or promote weight loss. Some attentional bias training trials are already underway and have demonstrated promising results for modifying late-stage attentional bias towards food cues⁵⁴. The present trial, and its focus on late-stage attentional bias, is designed to provide foundational knowledge for such future attentional bias training studies- altering conscious attentional bias towards food cues to influence eating behaviors and promote obesity

treatment. Future trials should focus on this aspect of attentional bias as these conscious processes governing eating behaviors is likely more relevant as we move forward towards these training studies.

Future research may also focus on whether there is an attentional bias towards low energy dense foods, such as vegetables, as most literature only considers energy dense foods. As noted, Graham et al. demonstrated that initial fixation direction was greater towards low-energy foods in the overweight/obese group compared to control²⁷. A better understanding as to why this was the case is needed, if it was a product of social desirability or if the presentation time was not long enough for participants to realize what they were looking at and focus on the high-energy dense foods. Future studies using percent fixation time to conceptualize attentional bias under conscious control is needed as this aspect of attentional bias is what future attentional bias training studies can target in attempting to promote changes in eating behaviors. A limited number of these training studies have been successful in altering attentional bias towards food cues^{47,55}, although it would be interesting to see if using a 3,000 ms presentation time and the percent fixation time metric would uncover additional information regarding changes in sustained fixation.

4.1 Limitations

The current study did not screen for eating disorders that would influence attentional bias towards food cues⁵⁶. However, none of the participants had a BMI that would be expected with the most common eating disorder, anorexia nervosa, with the lowest BMI at 18.8 and considered normal weight. Besides body fat and BMI, the groups differed on age, although age did not predict attentional bias when included in the regression model. We also did not assess demographic factors that may be predictors of attentional bias for food cues such as food security, household income, and education.

V. Conclusions

The primary results of the present trial supported those of previous trials which have indicated a possible link between attentional bias and weight status^{20,41,42,45}. The present trial expands on these previous findings by 1: increasing the presentation time to 3,000ms and focusing on late-stage attentional bias, 2: utilizing a novel "percent fixation time" metric to better conceptualize attentional bias towards food cues, and 3: performing these tests between meals in a state where participants were neither hungry or fully satiated. Such methodological intricacies are

important to consider when evaluating attentional bias for food cue research and making conclusions.

Conflicts of Interest, Funding, Data Sharing

Conflicts of interest: All authors declare that they have no conflicts of interest

Funding: The present study was supported by the National Institutes of Health P30GM127211 of the

National Institute of General Medical Sciences. The funding source had no involvement in data collection, analysis, interpretation or the decision to submit for publication.

Data Sharing: All data is publically available on FigShare at: 10.6084/m9.figshare.19104614.

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