Is there a memory bias for high-calorie food images?

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Submitted: October, 2020

Ethics: All studies were approved by the UCLA Institutional Review Board (IRB#19-000637) All participants provided consent before completing the study and were debriefed afterwards.

Preregistrations:

Exp 1: <https://osf.io/9j5sm>
Exp 2: <https://osf.io/tn8w4>

Open Data and Materials:

https://osf.io/79gz5/?view_only=5f8feefc7bfa4f16ba679b32746c8600

Abstract: It is unclear if, and to what extent, the human memory system is biased towards food and food relevant stimuli. Drawing upon existing demonstrations of attentional biases to high-calorie food images, and findings that evolutionarily relevant stimuli are preferentially remembered, we hypothesized that images of high-calorie foods would be better remembered than images of low-calorie foods and nonfood items. Investigating this is important because a general bias towards remembering high-calorie images might facilitate greater incentive learning towards these images which could result in cue-induced overconsumption. We tested this in two pre-registered, within-subject studies (Ns = 38). In Experiment 1, using a rapid stream visual presentation procedure and recognition memory test, we found no effect of image type (high-calorie, low-calorie, nonfood) on recognition for previously seen images. However, we did observe fewer correct rejections (i.e. more false memories) for novel low-calorie images. In Experiment 2, we used a longer encoding procedure and free recall memory test and similarly failed to observe an effect of image type on recall. We also did not observe a significant correlation between Body Mass Index (BMI) and a memory bias for high-calorie food images. We did however, discover several other factors that correlate with image memory. Given several theoretical positions that might predict this bias, we discuss possibilities as to why these experiments failed to produce such a bias, future directions for detecting it, and considerations if in fact such a mnemonic bias does not exist.

Key Words: Memory; Food Image; Incentive Salience, Adaptive Memory

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Do you remember what you ate for lunch yesterday? Many express difficulties recalling past meals, but of course, many also have difficulty remembering a whole host of recently experienced events. Is there any reason to expect memory for eating or food related stimuli to be any different than memory for any other type of behavior or other class of stimuli?

The potential for certain types of behaviors or stimuli to be preferentially remembered is often overlooked by those who study learning, memory, and information processing systems (Seitz, Blaisdell, Polack, & Miller, 2019). Common models of learning (e.g., Pearce & Hall, 1980; Rescorla & Wagner, 1972) allow for stimulus saliency to impact the rate of learning, but make no *a priori* predictions regarding whether certain types of stimuli are better remembered than others. Other learning models ignore how physical characteristics of a stimulus affect learning entirely (Schultz, Dayan, & Montague, 1997; Sutton & Barto, 1981). Dominant models of memory (e.g., Atkinson & Shiffrin, 1968; Craik & Lockhart, 1972; Rumelhart & McClelland, 1986) assume “information” enters the memory system without consideration of how different types of information can affect the likelihood that that information is remembered. Nevertheless, empirical demonstrations of biases in the human memory system are abundant. Animate stimuli are better remembered than inanimate stimuli (Gelin, Bonin, Méot, & Bugaiska, 2018; Nairne, VanArsdall, Pandeirada, Cogdill, & LeBreton, 2013), survival relevant information is better remembered than non-survival relevant information (Nairne & Pandeirada, 2016; Nairne, Thompson, & Pandeirada, 2007), pictures are better remembered than words (Shepard, 1967), and being the victim of a moral transgression is better remembered than being the perpetrator (Helion, Helzer, Kim, & Pizarro, 2019)—to name a few examples. Here, we ask whether there exists a mnemonic bias for high-calorie food images compared to low-calorie and nonfood images.

Why might such a bias exist? First, there is growing evidence that the human memory system is biased towards remembering evolutionary relevant stimuli. Because our mnemonic

abilities evolved to preferentially aid in fitness relevant tasks (e.g., survival, mating, etc.), some have argued that memory should prioritize information pertinent to those tasks (Nairne & Pandeirada, 2016). The first demonstration of this was provided by Nairne, Thompson, and Pandeirada (2007) who showed that words rated based on their relevance to an imagined survival situation were better remembered than those same words rated based on their relevance to a similarly worded imagined moving scenario. This “survival processing effect” has been replicated many times and recall rates continue to outperform other control scenarios (Nairne, Pandeirada, & Thompson, 2008; Scofield, Buchanan, & Kostic, 2018). Numerous other mnemonic biases that appear to be the result of evolutionary pressures have now been unearthed. As an example, Seitz, Polack, and Miller (2018) showed that words based on their relevance to an imagined parenting scenario similarly enhanced recall as compared to the survival scenario and outperformed scenarios unrelated to survival (building a monument). Follow up work has demonstrated that even altering the biological relatedness of the child in question (i.e. adopted vs biological) can influence recall (Bonin, Gelin, Laroche, & Méot, 2019; Seitz, Polack, & Miller, 2020, but see Krause et al., 2019). Other studies have demonstrated preferential memory for items potentially contaminated by a sick individual (Bonin, Thiebaut, Witt, & Méot, 2019; Fernandes, Pandeirada, Soares, & Nairne, 2017; Gretz & Huff, 2019) and for finding a mate (Pandeirada, Fernandes, Vasconcelos, & Nairne, 2017). Taken together, these and other studies suggest that the evolutionary significance of information encoded positively influences future recallability (Seitz et al., 2019).

Eating is perhaps the most frequently occurring evolutionarily important behavior that an individual must engage in. Given its importance to survival, one might expect eating to be particularly well remembered (Seitz, Tomiyama, & Blaisdell, 2020). Seitz, Blaisdell, and Tomiyama (2020) showed that eating behavior is better remembered than nearly identical procedural behaviors that do not involve eating. They also found that the caloric density of a food item consumed potentiates its ability to be remembered. Similarly, New, Krasnow, Truxaw,

and Gaulin (2007) had participants sample various items at a farmers market and then were asked to recall the locations of the various food stands where they tasted the items. They found a linear relationship between the caloric density of the food consumed and memory accuracy, with the location of more calorically dense items being better remembered. de Vries, de Vet, de Graaf, and Boesveldt (2020) recently replicated these results using a better controlled laboratory procedure. Pictures of high and low-calorie food images were presented on a map, and at test, participants showed enhanced spatial memory for the high-calorie images. While memory for the location of the high-calorie images was enhanced, it remains untested whether there is a bias to preferentially remember the high-calorie images themselves. From a functional perspective, a memory bias towards high-calorie foods would be advantageous as it would make food relevant information more memorable and thus more easily retrieved in guiding subsequent foraging behavior. In any event, these findings suggest there may be an evolved bias to preferentially remember high-calorie food stimuli compared to low-calorie or nonfood stimuli.

A separate literature within cognitive psychology that focuses on attentional processes also makes the prediction that there may exist a memory bias for high-calorie food images. Using a variety of attention-based tasks, a number of studies have reported an attentional bias for high-calorie versus low-calorie food stimuli as well as food versus nonfood stimuli. For instance, Mogg, Bradley, Hyare, and Lee (1998) found an attentional bias for food versus nonfood words using a simple dot-probe task. Cunningham and Egeth (2018) used a distractor task design whereby high-calorie, low-calorie, or nonfood items momentarily flashed in the periphery of the screen while participants completed a simple task, and found biased attention (i.e. more distraction) to high-calorie food images. Most recently, Ballesterio-Arnau, Moreno-Sánchez, & Cunillera (2021) observed an attentional bias to food stimuli versus nonfood stimuli using a novel task where participants were asked to hold previously seen images in working memory. This effect was not impacted by the valence, arousal, appeal, or caloric content of the

images, leading the authors to proclaim that “food is special by itself” in its ability to capture attention. With that said, it should be noted that not all studies have found these attentional biases to food images or have found that the bias can be explained by other factors such as hunger (e.g., Castellanos et al., 2009; Cunningham & Egeth, 2018) or eating styles (Nijs, Franken, & Muris, 2009). Others have explored whether or not attentional biases to food stimuli are more pronounced in individuals with overweight and obesity compared to individuals with normal Body Mass Index (BMI). While a number of studies have reported that attentional biases to food cues are heightened in individuals with overweight and obesity (Castellanos et al., 2009; Nijs, Muris, Euser, & Franken, 2010; Werthmann et al., 2011), others have not (Loeber et al., 2012; Pothos, Tapper, & Calitri, 2009), and the effect appears to be heavily influenced by the attentional bias task used (for reviews and meta-analyses, see Hagan, Alasmar, Exum, Chinn, & Forbush, 2020; Hendrikse et al., 2015; Werthmann, Jansen, & Roefs, 2015). While the exact parameters needed to observe this effect and its particular effect size are yet to be fully understood, the existence of a general attentional bias towards high-calorie food stimuli seems at the least, quite plausible and is supported by a number of studies. Similarly, while the role of attentional processes is still not entirely understood in influencing learning and memory, it is thought to be at least somewhat influential (Chun & Turk-Browne, 2007; Muzzio, Kentros, & Kandel, 2009; Oberauer, 2019). Thus, attentional biases towards high-calorie food items suggests similar biases might exist in memory.

If in fact there is a mnemonic bias towards high-calorie food images, this may have important implications in regard to the habitual control of eating and incentive salience (Berridge, Ho, Richard, & DiFeliceantonio, 2010). According to the model proposed by Berridge et al., cues paired with appetitive outcomes via Pavlovian associations become particularly salient and attractive as well as motivationally sought after (“wanted”) via dopaminergic mesolimbic pathways. In this manner, cues with high incentive value grab attention and motivate behaviors to obtain the associated reward (Bindra, 1978). These motivational values

are accelerated when the reward fulfills certain need states and thus can increase reward “wanting” while hedonic reward “liking” stays constant (Berridge, 2009; Berridge & Robinson, 2016). McDonald’s golden arches provide an illuminating example. As the association between the golden arches (stimulus) and tasty food (reward/outcome) grows, so too do the motivational properties of the golden arches, especially when the arches and food are experienced while hungry. Consequently, encountering the golden arches will cause one to “want” to go into McDonald’s to consume the food. This can result in overeating even if incongruent with one’s goals or hedonic preferences.

The incentive-salience model relates to a potential mnemonic bias for high-calorie food stimuli in two ways. First, as previously stated, cues with high incentive value are thought to be particularly salient and attractive (Berridge et al., 2010). This has often been used as a theoretical explanation for attentional biases towards food stimuli particularly in overweight and obese populations described earlier (Hagan et al., 2020). Similar reasoning is used to explain data from neuroimaging studies suggesting these populations show elevated reactivity to food cues in a variety of different brain regions (Boswell & Kober, 2016; Jastreboff et al., 2014; Leyton & Vezina, 2013; Stice, Spoor, Bohon, Veldhuizen, & Small, 2008). It follows, therefore, that increased neural activation and attention to high-calorie food stimuli and food predicting stimuli may have downstream effects on increasing memory for those stimuli. Second, the existence of an evolved mnemonic bias for high-calorie food stimuli is significant in light of this model, because of its reliance on learning associations between stimuli and rewarding food outcomes. If, for example, the memory system is biased towards remembering images of burgers and milkshakes from a food menu, the associations between these image cues and food reward may be particularly strong, resulting in increased “wanting” upon later experience with those cues.

Given these three theoretical reasons, it is important to establish whether or not there exists a bias in memory towards high-calorie food stimuli. To date, we know of only one study

that has indirectly assessed this question, and none that have directly addressed it. Morris and Dolan (2001) asked participants to remember sets of 10 images before taking part in multiple PET scans. The images were either appetizing food images taken from cookbooks or nonfood images consisting of household items (chairs, lamps, etc.), and participants were shown the images either while hungry or sated (within-subject design, 16-hour fast). A strong bias for recognizing food images was found while the participants were hungry, but this bias was reduced (but not eliminated) while participants were sated. These results are suggestive of a mnemonic bias towards high-calorie food items compared to nonfood items, but the small sample size ($N = 10$) undermines this finding (note: discovering a memory bias was not the primary aim of this study). Similarly, the selection of stimuli used in this study do not appear to be controlled for a variety of other features that could affect memory (e.g. image intensity, color, novelty, etc.). Thus, there is need to directly test the possibility of a mnemonic bias towards high-calorie food images using better powered, controlled, and open methodologies. We present two experiments, each using a different type of procedure to investigate a mnemonic bias towards high-calorie food images.

Experiment 1

The aim of this study was to assess the existence of a mnemonic bias towards high-calorie food images relative to low-calorie and nonfood images. We utilized a rapid stream visual presentation procedure to present participants with high-calorie, low-calorie, and nonfood images and then tested memory using a recognition memory test with familiar and novel images. We chose a rapid stream procedure because previous studies have found attentional biases for high-calorie images using similar procedures (e.g. Cunningham & Egeth, 2018). Our pre-registered hypothesis (https://osf.io/79gz5/?view_only=5f8feefc7bfa4f16ba679b32746c8600) was that high-calorie images should be better remembered than low-calorie and nonfood images.

Participants: A total of 38 (30 female, average age 20.2 years) UCLA undergraduates took part in this study to fulfill partial course credit. The sample size reflects a power analysis to detect a medium effect ($f = .25$) with 90% power, using a within-subject study design. The effect size was chosen to resemble the medium-sized attentional bias to high-calorie foods ($f = 0.30$) reported by Cunningham & Egeth (2018). The mean participant age was 20.2 (SD = 2.07) and the mean Body Mass Index was 22.1 (SD = 4.72). No other demographic variables were measured.

Stimuli and Materials: All images were selected from the extended *food-pics database* (<https://doi.org/10.3389/fpsyg.2014.00617>). These images are homogenous in their resolution, color depth, background color, and camera distance. There are also extensive measures such as macro-nutritional content, image characteristics, and normative data from 245 participants. We operationalized 3 categories of stimuli based on caloric density per 100 grams. High-calorie food images contained 300-800 kcal/100g, low-calorie food images contained 0-100 kcal/100g, and nonfood items were already identified in the *food-pics database*. We then pseudorandomly selected 20 images for each category, taking care to ensure there were no between group differences in any image characteristics (e.g., red, green, blue pixel counts, object size, complexity, etc.). While there were no between category differences for subjective image complexity, palatability, or craving, high-calorie images were perceived as being more arousing and having higher valence than the other two categories (see table 1 for full analysis and descriptive details of the stimulus categories). For the recognition test, an additional 20 images were chosen from each category and equated on all these measures (see S1). One strength of this study, therefore, is our stringent controlling of between category differences in the selected stimuli. The experimental program was created using PsychoPy v3 software (Peirce et al., 2019) and can be found here https://osf.io/79qz5/?view_only=5f8feefc7bfa4f16ba679b32746c8600. The programs were completed on individual computers (Dell 2-in-1 13.3" Laptop).

Procedure: Participants were instructed to not eat anything at least 2 hours prior to

arriving to participate in the study. The two-hour minimum fast was chosen because it had been successful in our lab for demonstrating a memory bias for *eating* high-calorie foods (Seitz et al., 2020; pre-print). Before completing the experiment, participants reported their age, sex, and time since last meal. They were then instructed that they would, “need to remember images that are presented to you very quickly” and that, “the images will appear for about a quarter of a second and will be presented in rapid succession.” After being reminded to do their best to remember each image, participants pressed the space bar to begin the experiment.

The 60 images (20 per category) were then presented to participants in a random order. Images lasted on the screen for 250ms and there was a 350ms Inter-Trial-Interval (ITI). The images were centered in the screen over a white background and measured 12x12 cm. The encoding phase, thus, lasted about 36 seconds. Following this, participants were instructed to complete as many simple algebra problems as possible on a handout provided in a folder next to the computer. This served as a distractor task and lasted for two minutes. After two minutes, the screen flashed red to orient the participant back to the computer. They then completed the recognition memory test. This consisted of being presented with 120 images, 60 of which were novel and the other 60 they had previously been presented. Of the 60 new images, 20 were high-calorie food images, 20 low-calorie food images, and 20 nonfood images. Images were presented sequentially in a random order and participants had 5s to indicate answer yes or no to the question, “Have you seen this image before?” Participants were then sequentially presented with the 20 high-calorie food images and 20 low-calorie food images they had initially been presented in the rapid stream procedure. For each image, they rated, “How much do you desire to eat this food?” on a scale from 1 (No desire to eat) – 5 (High desire to eat). The computer program then ended. Finally, participants had their heights and weights measured before being debriefed and given credit.

Results and Discussion: The threshold for significance of all statistical tests was set at $p < .05$.

A programming error led to 5 participants not completing the final “desire to eat” portion of the experiment. Otherwise, the data were in no other way constrained.

Figure 1a summarizes the total recognition memory for the 40 items in each category. This includes a possible 20 “hits” for correctly identifying previously shown items and 20 “correct rejections” for correctly identifying novel images. A repeated measures ANOVA revealed a significant main effect of image category on total recognition memory, $F(2, 74) = 15.533$, $p < 0.001$, $\eta^2 = 0.124$. Bonferroni-corrected comparisons revealed high-calorie images were significantly better recognized than low-calorie images, $t(37) = 4.349$, $p < 0.001$, $d = 0.705$, but not nonfood images, $t(37) < 1.0$. Similarly, nonfood images were better remembered than low-calorie images, $t(37) = 4.927$, $p < 0.001$, $d = 0.799$. However, these results appear to be entirely driven by aggregating hits with correct rejections. Figure 1b summarizes just the hits data, and a repeated measures ANOVA revealed no main effect of image type on correct hits, $F(2, 74) < 1.0$, with a Bayes factor of 10.58 in favor of the null. Meanwhile, Figure 1c summarizes the correct rejection data. A repeated measures ANOVA revealed a main effect of image type, $F(2, 74) = 40.176$, $p < 0.001$, $\eta^2 = 0.290$. Bonferroni-corrected comparisons showed higher correct rejection for high-calorie items compared to low-calorie images $t(37) = 6.909$, $p < 0.001$, $d = 1.121$. Nonfood images were more correctly rejected than low-calorie images $t(37) = 6.909$, $p < 0.001$, $d = 1.121$, $t(37) = 7.285$, $p < 0.001$, $d = 1.182$, and high-calorie images, but this was not significant following the Bonferroni correction, $t(37) = 2.312$, $p = 0.079$, $d = 0.375$. A memory bias for high-calorie images score was generated by subtracting the number of low calorie items correctly recognized or rejected from the number of high-calorie items correctly recognized or rejected (high scores indicate higher bias) and this score did not significantly correlate with BMI, *Pearson’s* $r = 0.029$, $p = 0.864$. Finally, we conducted each analysis again with time since last meal as a covariate and sex as a between subject factor but neither factor nor any interactions were significant (lowest p value = 0.07). That there was no effect of gender suggests, albeit

indirectly, that restrained eating did not influence memory performance, as restrained eating is significantly more prevalent in women (Johnson, Pratt, & Wardle, 2012; Savage, Hoffman, & Birch, 2009)—but we were not well powered to make such claims.

Why were newly presented high-calorie and nonfood images more correctly rejected than low-calorie images? One possibility is that the low-calorie images fell prey to the Deese-Roediger-McDermott (DRM) effect (Roediger & McDermott, 1995). The DRM effect is when false memories are created by presenting wordlists of semantically related words (e.g., snow, winter, jacket). On later recognition tests, participants often indicate having seen the word “cold” even though it was not presented during the initial encoding phase. Thus, participants might have poorly rejected novel low-calorie images (indicating high rates of “false alarms”) because the images were more semantically related than the high-calorie image or nonfood images. More specifically, by their very nature, low-calorie food images were mostly limited to various fruits and vegetables whereas there was much more variability in the types of high-calorie and nonfood images. To alleviate some of these concerns, in Experiment 2 we utilized a free-recall procedure. A free-recall procedure is less likely to result in such “false memories” because the items are not suggested to participants who must then make a forced choice.

It is also of interest to ask what characteristics of an image correlate with its being remembered. That is, for each image, we could calculate the percentage of participants ($x/38$) who correctly identified (hit) or rejected the image and correlate that with the large number of measures associated with each image. While this type of analysis was exploratory and possibly susceptible to multiple comparison effects, we felt these analyses would elucidate potential factors that can influence image memorability.

Bivariate correlations were conducted with correct memory identification and various metrics associated with each image. For the items actually seen, the amount of carbs per 100 grams was significantly correlated with the percentage of participants who recognized that image, $r = 0.344$, $p = 0.030$ (see Figure 2a). Image subjective recognizability, $r = 0.531$, $p <$

0.001 (see Figure 2b), and subjective familiarity, $r = 0.346$, $p = 0.007$ (see Figure 2c), were also significantly correlated with hit rate, despite not varying between image categories. Protein, fat, and caloric density did not correlate with image hit rate, nor did red, green, or blue pixel counts, or object size, intensity, contrast, complexity. Finally, there were no significant correlations between item memorability and its subjective valence, arousal, palatability, complexity, or craving (lowest p value = 0.23), as rated by the 245 participants in the *food-pics* database (Blechert, Lender, Polk, Busch, & Ohla, 2019). Though for our participants there was a significant difference in the rated desirability of the food pictures, such that high-calorie food pictures were rated as more desirable than low-calorie images $F(1,32) = 10.058$, $p = 0.003$, $\eta^2 = 0.105$, there was not a significant correlation between the average desire rating of each image and the percentage of participants who recognized that image, $r = 1.65$, $p = 0.309$. For the 60 novel images, there were significant correlations between correct rejections and item carbohydrate density, $r = 0.477$, $p = 0.002$ (Figure 2d), item caloric density, $r = .469$, $p = 0.002$ (Figure 2e), subjective palatability, $r = -3.84$, $p = 0.015$ (Figure 2f), subjective valence, $r = -.510$, $p < 0.001$ (Figure 2g), and arousal $r = -4.04$, $p = 0.001$ (Figure 2h). There were no significant correlations between correct rejection and item protein or fat content, nor image red, green, or blue pixel counts. There was also no correlation between correct rejection and subjective item craving, complexity, recognizability, or familiarity (lowest p value = 0.06 [fat per 100g]).

In conclusion, using a rapid stream procedure, we found enhanced overall memory for high-calorie and nonfood images compared to low-calorie food images. However, there was no effect of image type on correctly identifying previously seen images, and the observed effect was due to lower calorie images being more likely to be falsely remembered (i.e. low correct rejection) compared to high-calorie and nonfood images. For images previously seen, carbohydrate density, subjective recognizability, and familiarity of the image were correlated with being correctly identified, and for novel images, carbohydrate density, caloric density, subjective palatability, valence, and arousal were correlated with correct rejections. That these

measures are correlated with either memory hits and/or correct rejection rates suggests the need to control for potential between category differences in these measures when selecting stimuli.

Experiment 2

In the experiment above, we did not find evidence of a meaningful mnemonic bias towards high-calorie food images. One explanation for these null effects is perhaps due to our use of a rapid stream encoding procedure and/or our use of recognition memory task. Thus, in Experiment 2, we utilized a more traditional and longer encoding procedure and a simple free-recall task. This procedure more closely mimics that of experiments that have identified memory biases to evolutionary significant information (e.g., Nairne et al. 2007). Our pre-registered hypothesis was that high-calorie food images should be better recalled than low-calorie and nonfood images.

Participants: A total of 38 (29 female, average age 20.4 years) UCLA undergraduates took part in this study to fulfill course credit. The sample size reflects a power analysis to detect a medium effect ($f = .25$) with 90% power, using a within-subject study design. The mean participant age was 20.4 (SD = 1.60) and the mean Body Mass Index was 23.78 (SD = 5.61). No other demographic variables were measured.

Stimuli and Materials: Thirty images were pseudorandomly chosen from the *food-pics* database and categorized into three groups based on the same criteria as Experiment 1. There were no between group differences between high-calorie images, low-calorie images, or nonfood images in image characteristics or subjective characteristics, which was related to correct rejection rates in Experiment 1 (see table 2 for between group comparisons). All other materials were identical to that used in Experiment 1.

Procedure: Participants were instructed to not eat anything at least 2 hours prior to arriving to participate in the study. Before starting the experiment, participants reported their age, sex, and time since last meal. They were then instructed that they would, “remember images that are

presented to you” and that, “The images will appear for a total of 5 seconds each. All you have to do is watch.” After being reminded to do their best to remember each image, participants pressed the space bar to begin the experiment.

The 30 images (10 per category) were then presented to participants in a random order. Images lasted on the screen for 500ms and there was a 100ms ITI. The images were centered in the screen over a white background and measured 12x12 cm. The encoding phase, thus, lasted just under 3 minutes. Participants then completed the same distractor task (solving algebra problems) as in Experiment 1. After two minutes, the screen flashed red to orient the participant back to the computer. They were then told that, “You will have 5 minutes to write down a description of each picture you were shown. Please write one description per line. These do not need to be overly detailed. For instance, if you were shown the image below [Picture of a Bernese-Mountain Dog], an appropriate description would be, “dog.” Participants completed the free recall portion on paper with pencils provided to them.

Following the five-minute free recall period, the screen flashed red to orient participants back to the computer. Participants were then sequentially presented with the 30 previously presented images and asked to rate the desirability of each item, just as in Experiment 1. The computer program then ended. Finally, participants had their heights and weights measured before being debriefed and given credit.

Results and Discussion: The recall data were scored by 2 independent reviewers. All inconsistencies were then reviewed by the PI. Of the few inconsistencies identified, none were due to differing interpretations of the recalled items, and all were due to simple mistakes (e.g., forgetting to input an item [omission]). A programming error led to 11 participants not completing the final “desire to eat” portion of the experiment. The data were in no other way constrained.

A summary of the recall data by category is provided in Figure 3a. A repeated measures ANOVA revealed no effect of image type on recall $F(2, 74) < 1.0$, Bayes factor of 8.477 in favor of the null. A bias towards remembering high-calorie items was positively correlated with

participant BMI, but did not reach statistical significance, $r = 0.288$, $p = 0.080$. When the original model was re-analyzed with time since last meal as a covariate, and sex as an additional factor, image type remained not significant, $F(2, 70) = 1.599$, $p = 0.209$, sex was not significant, $F(1) = 2.497$, $p = 0.123$, and time since last meal was not a significant covariate, $F(1, 35) < 1.087$, $p = 0.304$. There was no interaction between sex and image type, $F(2, 70) = 1.914$, $p = 0.155$. This provides a second demonstration indicating a lack of a mnemonic bias towards high-calorie food images compared to low-calorie and nonfood images.

While there were no between category differences in any of the image characteristics provided by the *food-pics* database, we used bivariate correlations to explore any associations between image memorability and image characteristics. Image contrast (Figure 3b), $r = 0.366$, $p = 0.047$, subjective valence (Figure 3c), $r = 0.373$, $p = 0.043$, and subjective arousal (Figure 3d), $r = 0.370$, $p = 0.044$, were all associated with the image being more likely recalled. No other image characteristics, including macronutrient contents (e.g., fat, carbs, protein, or kcal density), objective image characteristics (e.g. red, green, blue pixel counts, object size, intensity, or complexity), or subjective image characteristics (e.g., recognizability, familiarity, complexity, or craving) were related to the percent of participants who recalled the image (lowest p value = 0.123). While there was a significant difference in the participant-rated desirability of the food pictures, such that high-calorie food pictures were rated as more desirable than low-calorie images $F(1,26) = 9.268$, $p = 0.005$, $\eta^2 = 0.118$, there was no relationship between the average desire rating of each food image and the percentage of participants that recalled it, $r = 0.022$, $p = 0.927$.

Conclusion

Two experiments sought to explore the existence of a mnemonic bias towards high-calorie food stimuli. Attentional biases to high-calorie food stimuli have previously been reported (Hagan et al., 2020; Mogg et al., 1998) and there are also mnemonic biases towards remembering the consumption (Seitz, et al., 2020) and location (de Vries et al., 2020; New et

al., 2007) of high-calorie foods. A bias towards high-calorie food stimuli could also facilitate the incentive value of food cues, thus resulting in overconsumption (Berridge et al., 2010).

Nonetheless, we failed to find any evidence of such a bias using both a rapid stream visual presentation procedure coupled with a recognition memory task or a more traditional encoding procedure with a free recall memory task. We also found no evidence to that BMI was related to a mnemonic bias towards high-calorie images. These results are congruent with a recent report by (Ballesterio-Arnau et al., 2021) who asked participants to hold images of food (or nonfood images) in working memory before completing an RSVP task. While the aim of this study was ultimately to probe for an attentional bias towards food images—which indeed they found—they too did not observe enhanced memory for the food images compared to images of nonfood. That said, in experiment 3, they did observe better recall for unprocessed food compared to transformed food.

Why did we not observe a mnemonic bias towards high-calorie food images? One possibility is that hunger moderates this effect, and our participants were not hungry enough. This is supported by the fact that attentional biases to food cues are exacerbated in hungry compared to sated participants (Stockburger, Schmälzle, Fleisch, Bublatzky, & Schupp, 2009; but see Ballesterio-Arnau et al., 2021). However, others have found attentional biases to food cues without explicit instructions for participants to fast (e.g., Cunningham & Egeth, 2018) and we asked our participants not to eat at least 2 hours before completing the study. Furthermore, 16% of participants in Experiment 1 and 34% of participants in Experiment 2 reported their last meal being over 10 hours ago, and time since last meal was not a significant covariate of memory in either study. It is possible that the other features of the experimental procedure were not optimal for discovering this effect. The rapid stream procedure was chosen to mimic attentional biases observed to rapidly presented images (e.g., Cunningham & Egeth, 2018) and the free recall procedure with a longer encoding phase to mimic procedures that have observed other evolutionary biases to memory (e.g., Nairne et al., 2007). However, these may have been

inappropriate for reasons we have yet to consider, and other procedures (e.g., paired-associates task) might be better suited for demonstrating this potential bias. Finally, it is possible that while high-calorie images can capture attention better than low-calorie images, that attentional bias does not translate to a memory bias for those images. While we have shown biased memory for the consumption of high-calorie foods and others have shown biased memory for the location of high-calorie food images, there might be no benefit to preferentially remembering the high-calorie images themselves compared to low-calorie or nonfood images.

We can confidently report that this null effect was not the result of poor stimulus selection. Thanks to the extensive metrics associated with each image provided in the *food-pics* database, we were able to choose stimuli such that there were minimal between group differences in basic image characteristics or their subjective qualities. Even after controlling for these factors, exploratory analyses suggested several factors that correlate with image recognition or recall, which suggests the importance of controlling for such factors during stimulus selection of any image-based memory task. Lastly, while we were well powered to detect a medium effect ($f = .25$ with over 90% power) based on similar effects in attentional biases, if the true effect size is smaller (e.g., $f = 0.15$) we would have only achieved around 50% power. Thus, future studies should consider these estimates when determining sample size.

In conclusion, despite several well-grounded theoretical reasons to suspect a mnemonic bias towards high-calorie food images, we did not observe this effect using both a recognition and free recall memory task. Given the theoretical basis (attentional bias and evolutionary theory) that predict this bias, and the potential applied implications (incentive salience theory), others should similarly explore its potential existence, using similar and novel approaches.

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Acknowledgments: The authors are grateful to Selina Hsuan, Roxanne Cooke, and Ayla Boghikian for collecting the data. This research was funded in part by the American Psychological Association of Graduate Students Psychological Science Research Grant. Benjamin Seitz is supported by National Science Foundation Grant DGE-1650604.

Table and Figure Captions:

Table 1: Between category differences in image characteristics used in the rapid stream visual presentation task in experiment 1 as provided by *food-pics* database. HC = high-calorie, LC = low-calorie, NF = nonfood images.

Table 2: Between category differences in image characteristics used in Experiment 2 as provided by *food-pics* database. HC = high-calorie, LC = low-calorie, NF = nonfood images.

Figure 1: Recognition data from Experiment 1. **a)** Total recognition score including “hits” and “correct rejections” per stimulus category (out of 40). **b)** Correctly identifying previously seen images, “hits,” per stimulus category (out of 20). **c)** Correctly identifying novel images, “correct rejections,” per stimulus category (out of 20). *** indicates p -value < 0.001.

Figure 2: Correlates of image recognition in Experiment 1. Shaded area represents 95% confidence intervals. **a)** Previously seen image hit rate correlates with carbohydrate density. **b)** Previously seen image hit rate correlates with subjective recognizability. **c)** Previously seen image hit rate correlates with subjective familiarity. **d)** Novel image correct rejection rate correlates with carbohydrate density. **e)** Novel image correct rejection rate correlates with caloric density. **f)** Novel image correct rejection rate correlates with subjective palatability. **g)** Novel image correct rejection rate correlates with subjective valence. **h)** Novel image correct rejection rate correlates with subjective arousal.

Figure 3: Recall data and image correlates in Experiment 2. Shaded area represents 95% confidence intervals. **a)** Total recall per stimulus category (out of 10). **b)** Image contrast correlates with recall. **c)** Image subjective valence correlates with recall. **d)** Image subjective arousal correlates with recall.

S1: Between category differences in novel image characteristics for the recognition memory test in experiment 1 as provided by *food-pics* database. HC = high-calorie, LC = low-calorie, NF = nonfood images.

	Df	F	p value	eta squared	HC Mean	HC SD	LC Mean	LC SD	NF Mean	NF SD
protein per 100 g	(1, 38)	15.46	< 0.001	0.29	9.65	9.04	1.65	0.94		
fat per 100 g	(1, 38)	46.98	< 0.001	0.55	27.08	17.43	0.36	0.30		
carbs per 100 g	(1, 38)	33.69	< 0.001	0.47	40.59	26.73	5.61	3.40		
kcal per 100 g	(1, 38)	246.18	< 0.001	0.87	444.70	116.12	34.10	14.55		
no items image	(1, 38)	2.05	0.161	0.05	6.39	11.54	16.10	28.08		
grams total	(1, 38)	2.17	0.149	0.05	185.97	258.16	343.13	401.51		
protein total	(1, 38)	3.61	0.065	0.09	21.36	36.79	5.46	6.93		
fat total	(1, 38)	15.10	< 0.001	0.28	44.13	49.44	1.14	1.94		
carbs total	(1, 38)	3.15	0.084	0.08	58.13	101.30	17.18	19.40		
Kcal total	(1, 38)	9.43	0.004	0.20	732.57	905.93	105.61	112.45		
red	(2, 57)	0.08	0.92	0.00	0.47	0.06	0.46	0.11	0.46	0.11
green	(2, 57)	0.16	0.854	0.01	0.32	0.04	0.33	0.08	0.33	0.08
blue	(2, 57)	0.14	0.868	0.01	0.21	0.04	0.21	0.06	0.22	0.07
object size	(2, 57)	0.17	0.847	0.01	0.31	0.08	0.31	0.11	0.30	0.11
intensity	(2, 57)	0.35	0.71	0.01	35.96	11.57	37.33	15.89	33.35	18.23
intensity norm	(2, 57)	0.27	0.765	0.01	120.16	41.78	123.18	33.69	114.69	35.36
contrast sd	(2, 57)	0.13	0.88	0.00	3.58	13.76	55.06	11.71	52.77	17.49
complexity	(2, 57)	1.31	0.279	0.04	0.10	0.04	0.11	0.05	0.08	0.05
complexity norm	(2, 57)	0.75	0.478	0.03	0.32	0.12	0.35	0.08	0.30	0.13
spatial frequencies	(2, 57)	0.17	0.846	0.01	15.78	1.14	15.81	1.15	15.62	1.11
Recognizability all	(2, 57)	0.42	0.662	0.01	96.12	6.65	97.85	4.48	96.62	6.94
Familiarity all	(2, 57)	0.53	0.593	0.02	95.77	5.61	97.55	5.04	95.90	7.32
Valence all	(2, 57)	13.47	< 0.001	0.32	51.44	6.40	62.21	8.45	50.57	8.65
Arousal all	(2, 57)	4.32	0.018	0.13	33.72	6.27	33.87	10.08	26.19	11.25
Complexity all	(2, 57)	0.10	0.909	0.00	33.95	9.99	32.58	9.64	32.61	13.89
Palatability all	(1, 38)	1.85	0.182	0.05	56.08	7.76	60.28	11.42		
Craving all	(1, 38)	0.22	0.645	0.01	32.40	7.43	34.06	14.12		

Table 1: Between category differences in image characteristics used in the rapid stream visual presentation task in experiment 1 as provided by *food-pics* database. HC = high-calorie, LC = low-calorie, NF = nonfood images.

	Df	F	p value	eta squared	HC Mean	HE SD	LC Mean	LE SD	NF Mean	NF SD
protein per 100 g	(1, 38)	15.79	< 0.001	0.47	10.32	7.24	1.17	0.73		
fat per 100 g	(1, 38)	22.83	< 0.001	0.56	22.98	14.92	0.43	0.46		
carbs per 100 g	(1, 38)	14.78	0.001	0.45	40.48	28.16	5.71	4.99		
kcal per 100 g	(1, 38)	131.39	< 0.001	0.88	413.30	102.15	34.00	22.71		
no items image	(1, 38)	0.99	0.334	0.05	36.35	93.39	6.88	9.38		
grams total	(1, 38)	1.45	0.243	0.08	210.10	235.86	364.35	328.64		
protein total	(1, 38)	1.76	0.202	0.09	29.99	58.15	5.46	6.66		
fat total	(1, 38)	5.40	0.032	0.23	52.54	69.49	1.43	2.58		
carbs total	(1, 38)	1.22	0.283	0.06	47.76	49.21	26.10	37.58		
Kcal total	(1, 38)	5.68	0.028	0.24	787.23	831.07	145.51	186.88		
red	(2, 57)	0.27	0.764	0.02	0.45	0.04	0.44	0.10	0.42	0.13
green	(2, 57)	0.65	0.529	0.05	0.33	0.03	0.36	0.08	0.33	0.11
blue	(2, 57)	1.68	0.205	0.11	0.22	0.05	0.20	0.06	0.26	0.10
object size	(2, 57)	1.05	0.365	0.07	0.34	0.07	0.29	0.07	0.30	0.11
intensity	(2, 57)	0.27	0.768	0.02	35.00	10.83	31.20	15.16	31.30	13.46
intensity norm	(2, 57)	0.04	0.964	0.00	105.72	34.31	110.08	42.90	109.24	36.73
contrast sd	(2, 57)	0.31	0.733	0.02	52.32	7.72	49.07	14.79	55.11	24.38
complexity	(2, 57)	1.48	0.246	0.10	0.12	0.04	0.09	0.05	0.09	0.06
complexity norm	(2, 57)	0.76	0.479	0.05	0.37	0.11	0.33	0.14	0.30	0.14
spatial frequencies	(2, 57)	2.27	0.122	0.14	15.80	1.13	15.27	0.92	16.30	1.20
Recognizability all	(2, 57)	1.74	0.195	0.14	98.79	2.58	98.59	4.11	88.82	23.16
Familiarity all	(2, 57)	0.36	0.704	0.03	97.40	4.12	98.37	3.81	96.20	8.27
Valence all	(2, 57)	1.90	0.169	0.12	51.09	10.29	59.58	5.92	55.46	12.00
Arousal all	(2, 57)	1.03	0.369	0.07	34.95	7.43	32.51	7.31	28.67	13.50
Complexity all	(2, 57)	2.73	0.083	0.17	34.01	8.65	27.15	6.22	36.96	12.84
Palatability all	(1, 38)	0.12	0.73	0.01	56.58	11.51	58.29	10.24		
Craving all	(1, 38)	0.08	0.778	0.01	36.26	8.44	34.93	12.13		

Table 2: Between category differences in image characteristics used in Experiment 2 as provided by *food-pics* database. HC = high-calorie, LC = low-calorie, NF = nonfood images.

Figure 1: Recognition data from Experiment 1. **a)** Total recognition score including “hits” and “correct rejections” per stimulus category (out of 40). **b)** Correctly identifying previously seen images, “hits,” per stimulus category (out of 20). **c)** Correctly identifying novel images, “correct rejections,” per stimulus category (out of 20). *** indicates p -value < 0.001.

Figure 2: Correlates of image recognition in Experiment 1. Shaded area represents 95% confidence intervals. **a)** Previously seen image hit rate correlates with carbohydrate density. **b)** Previously seen image hit rate correlates with subjective recognizability. **c)** Previously seen image hit rate correlates with subjective familiarity. **d)** Novel image correct rejection rate correlates with carbohydrate density. **e)** Novel image correct rejection rate correlates with caloric density. **f)** Novel image correct rejection rate correlates with subjective palatability. **g)** Novel image correct rejection rate correlates with subjective valence. **h)** Novel image correct rejection rate correlates with subjective arousal.

Figure 3: Recall data and image correlates in Experiment 2. Shaded area represents 95% confidence intervals. **a)** Total recall per stimulus category (out of 10). **b)** Image contrast correlates with recall. **c)** Image subjective valence correlates with recall. **d)** Image subjective arousal correlates with recall.

Supplemental Material

	Df	F	p value	eta squared	HC Mean	HE SD	LC Mean	LE SD	NF Mean	NF SD
protein per 100 g	(1, 38)	25.53	< 0.001	0.40	10.06	7.51	1.38	1.63		
fat per 100 g	(1, 38)	51.93	< 0.001	0.58	21.50	13.05	0.43	0.87		
carbs per 100 g	(1, 38)	52.63	< 0.001	0.58	46.74	24.33	6.65	4.38		
kcal per 100 g	(1, 38)	439.19	< 0.001	0.92	414.89	77.75	35.89	22.29		
no items image	(1, 38)	0.39	0.535	0.01	3.60	3.76	5.54	13.32		
grams total	(1, 38)	4.27	0.046	0.10	137.03	145.84	364.47	470.10		
protein total	(1, 38)	3.05	0.089	0.07	19.64	37.82	4.61	7.08		
fat total	(1, 38)	9.38	0.004	0.20	36.63	51.01	1.61	3.64		
carbs total	(1, 38)	3.54	0.067	0.09	40.84	37.49	21.78	25.41		
Kcal total	(1, 38)	10.66	0.002	0.22	558.16	585.10	120.33	131.20		
red	(2, 57)	0.02	0.979	0.00	0.45	0.04	0.45	0.09	0.45	0.08
green	(2, 57)	0.34	0.713	0.01	0.34	0.03	0.35	0.05	0.34	0.03
blue	(2, 57)	0.06	0.945	0.00	0.21	0.04	0.21	0.06	0.21	0.09
object size	(2, 57)	0.11	0.896	0.00	0.31	0.81	0.30	0.08	0.30	0.11
intensity	(2, 57)	0.79	0.461	0.03	31.32	9.53	27.31	12.25	27.08	13.88
intensity norm	(2, 57)	0.84	0.437	0.03	102.64	25.79	91.56	34.50	91.09	34.61
contrast sd	(2, 57)	0.05	0.947	0.00	48.39	13.17	48.18	13.94	49.72	20.10
complexity	(2, 57)	0.56	0.575	0.02	0.10	0.03	0.09	0.04	0.09	0.05
complexity norm	(2, 57)	0.43	0.652	0.02	0.33	0.12	0.29	0.10	0.31	0.15
spatial frequencies	(2, 57)	0.62	0.544	0.02	15.31	0.88	0.64	1.23	15.73	1.53
Recognizability all	(2, 57)	0.60	0.555	0.02	96.97	13.87	99.47	1.14	96.74	6.17
Familiarity all	(2, 57)	0.12	0.889	0.00	96.01	10.11	97.32	4.42	95.88	14.19
Valence all	(2, 57)	19.80	< 0.001	0.41	49.13	7.93	59.61	6.96	45.45	7.24
Arousal all	(2, 57)	23.05	< 0.001	0.45	31.55	7.55	33.63	6.91	19.07	7.53
Complexity all	(2, 57)	0.99	0.378	0.03	29.17	4.43	30.70	6.24	27.08	11.89
Palatability all	(1, 38)	5.20	0.028	0.12	52.01	10.35	59.37	10.07		
Craving all	(1, 38)	2.72	0.107	0.07	30.49	8.86	35.27	9.25		

S1: Between category differences in novel image characteristics for the recognition memory test in experiment 1 as provided by *food-pics* database. HC = high-calorie, LC = low-calorie, NF = nonfood images.