Acta Psychologica 244 (2024) 104192

Contents lists available at ScienceDirect

Acta Psychologica

journal homepage: www.elsevier.com/locate/actpsy

Effects of hunger and calorie content on visual awareness of food stimuli

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ARTICLE INFO

Keywords:
Food
Visual awareness
Hunger
Calorie
Binocular rivalry
Breaking continuous flash suppression

ABSTRACT

Calorie content and hunger are two fundamental cues acting upon the processing of visually presented food items. However, whether and to which extent they affect visual awareness is still an open question. Here, high- and low-calorie food images administered to hungry or satiated participants were confronted in a breaking-Continuous Flash Suppression paradigm (Experiment 1), measuring the time required to access to visual awareness, and in a Binocular Rivalry paradigm (Experiment 2), quantifying the dominance time in visual awareness. Experiment 1 showed that high-calorie food accessed faster visual awareness, but mostly in satiated participants. Experiment 2 indicated that high-calorie food dominated longer visual awareness, regardless the degree of hunger. We argued that the unconscious advantage (Experiment 1) would represent a default state of the visual system towards highest-energy nutrients, yet the advantage is lost in hunger so to be tuned towards an increased need for any nutritional category. On the other hand, the conscious advantage of high-calorie food (Experiment 2) would represent a conscious perceptual and attentional bias towards highest energy-dense food useful for the actual detection of these stimuli in the environment.

1. Introduction

Feeding constitutes a fundamental biological need for human species, and dieting has been overly critical for our evolution. The actual food intake is driven by a series of biological mechanisms that strictly regulate the optimal levels of nutrients in the bloodstream and bodily stores. In the very distant past, these processes reliably ensured the acquisition of energy in environments characterized by limited food resources. Nonetheless, in modern societies, marked by abundance of palatable foods, additional non-homeostatic factors (e.g., sight, smell, taste, environmental cues) significantly trigger feeding behavior and potentially increase the risk of unhealthy habits. Consequently, nowadays both homeostatic and non-homeostatic variables jointly operate in a highly synergistical manner to promote our nutritional attitudes. Hence, understanding such complex interplay is fundamental in terms for basic research and clinical interventions.

There is a wide consensus that two key variables affect actual eating behavior, namely the salience of food stimuli and the feeling of hunger (Emilien & Hollis, 2017). Interestingly, they are often investigated within the visual domain, given that the identification of nutritional sources is a highly vision-dependent activity. Indeed, the sight allowed our ancestors to actively explore the entire surrounding environment, particularly the distant areas in order to detect nutrients. This, in turn, significantly increased the likelihood of survival. In the context of visual salience, the calorie content is a fundamental feature for optimizing the detection of energy resources. The calorie content can indeed facilitate eating through a variety of modulatory effects, such as boosting arousal (Blechert et al., 2014), or strengthening the perceived pleasantness (Ohla et al., 2012). As regards hunger, it is known that food deprivation is the core cue towards eating behavior as a high-priority biological activity (Atasoy et al., 2012). Hunger can facilitate eating for instance, by enhancing its reward properties (Cameron et al., 2014; Siep et al., 2009) or the memory encoding of food items (Morris & Dolan, 2001). Moreover, given the above-mentioned fundamental role of the visual system in feeding behavior, it is also crucial examining whetherand to which extent, the complex interplay between hunger and calorie content might affects the visual awareness of food stimuli. Indeed, it is known that the potentiality of the visual system with or without conscious awareness are tightly related to evolutionary needs (Reber, 1992) and functional differences (e.g., semantic processing, spatiotemporal

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https://doi.org/10.1016/j.actpsy.2024.104192
Received 12 October 2023; Received in revised form 5 February 2024; Accepted 13 February 2024
Available online 19 February 2024

integration (Ludwig, 2023). Whether the homeostatic state might influence early visual perception congruently with the organism needs is worth investigating. Capitalizing on all this evidence, exploring the role of calorie content and hunger on visual awareness of food stimuli, is a topic well-suited for scientific investigation.

In this study, we examined whether and how calorie content and hunger affect prioritization of food stimuli in visual awareness. In particular, we focused on two distinct aspects of visual awareness, which are the access to, and the dominance in. With respect to the access to, we employed the breaking-Continuous Flash Suppression (bCFS) paradigm (Jiang et al., 2007). It is well known that when a salient image is administered to one eye and a low salient image to the other, the latter is suppressed from conscious perception. This paradigm, known as Continuous Flash Suppression (CFS; (Tsuchiya and Koch, 2005)), is useful to study the unconscious visual processing. One of its variants, the so-called breaking Continuous Flash Suppression (bCFS), measures the time that the target needs to break the suppression induced by the salient stimulus, which often is a high-contrast Mondrian-like visual pattern (i.e., dynamically changing geometrical-colored shapes), whereas the non-salient stimulus (i.e., the target) is a static, low-contrast image. The idea is that thestimulus that overcomes the interocular suppression faster, enabling its conscious access, is perceptually prioritized before awareness (Stein, 2019; Stein, Hebart, & Sterzer, 2011). In other words, bCFS rely on a direct index of conscious perception that allows to infer differential unconscious processing (specifically, the time a given stimulus needs to be consciously detected). For the perceptual dominance, it is important to emphasize, as first, that our brain cannot unify different images seen by the two eyes. This phenomenon occurs in the Binocular Rivalry (BR) paradigm in which two images are presented to both eyes, and conscious perception typically alternates between the two stimuli that compete for conscious representation. The reported stimulus (consciously perceived at the moment) is known as dominant, the unreported one (unconsciously perceived at the moment) is named suppressed (Tong et al., 2006). BR has been largely employed to examine both low-level and higher-level effects on visual awareness (Brascamp, Klink, & Levelt, 2015; Tong, Meng, & Blake, 2006; Wolf & Hochstein, 2011), with the rationale that the stimuli being reported for longer time (i.e., perceptually dominant and more likely to be consciously perceived) are prioritized in conscious visual awareness.

Summarizing, here we compared high-calorie vs. low-calorie content of food images presented in a condition of hunger vs. satiety, and we measured the time of access (Experiment 1) and the time of dominance (Experiment 2) in visual awareness. Moreover, we administered three questionnaires assessing food and body attitudes in order to explore a potential link between individual traits and awareness timings. Indeed, some studies showed that personality traits can correlate with bCFS responses (Schmack et al., 2016) with the idea that an individual meaning given to stimuli can be associated to visual awareness measures (Stein, 2019). We administered three scales (Drive for thinness, Bulimia, Body Dissatisfaction) taken from the Eating Disorder Inventory-3 (Garner, 2004), the Body Perception Questionnaire (Porges, 1993), and the Multidimensional Assessment of Interoceptive Awareness (Mehling et al., 2012) to explore whether, eating disorder attitudes, body awareness, and interoceptive awareness traits, respectively, might be associated with the processing of high- and low-calorie stimuli in visual awareness. These scales were correlated to the results of our experiments. Given the crucial evolutionary relevance of calorie content and hunger to eating behavior, we predicted that these two cues would have differentially affected visual awareness of food stimuli. Specifically, we expected that high-calorie content (with respect to low-calorie content) would have been unconsciously prioritized and perceptually dominating, with hunger (compared to satiety) possibly enhancing such prioritization, assuming that a top-down homeostatic processing could modulate visual perception.

2. Materials and methods

2.1. Participants

Forty-two individuals (24 F, mean age = 24.64, SE = ± 0.58) were recruited for the study (started 01/01/2021 and ended 12/30/2022) after having provided a written informed consent. They were all right or left-handed with normal or corrected-to-normal vision and reported no psychiatric or neurological history. The study was previously approved by the Ethical Committee of the University of Turin (protocol n. 0630171) and performed in accordance with relevant guidelines of the declaration of Helsinki. Sample size was similarly based on studies using such paradigms (Lee et al., 2022; Weng et al., 2019).

Participants arrived to the laboratory, having already completed the questionnaires which assessing food and body attitudes via Google modules and measurements for height and weight were taken (in order to calculate their Body Mass Index-BMI). They were asked to arrive at the laboratory around 2 p.m., with half of them in a fasting condition, since awake, whereasthe other half after having consumed both breakfast and lunch. Nonetheless, to strengthen the validity of the construct 'hunger', at their arrival participants were asked to rate their level of actual hunger on a 1–5 Likert scale (1 = not hungry at all, 5 = very hungry). Among fasting participants, we decided to select only those with a hunger rating of 4 or 5, whereas among the satiated participants only those with 1 or 2. Consequently, thirty participants were selected for the study, fifteen within the 'hunger group' and fifteen within the 'satiated group'. In order to control for the potential influence of affective/cognitive variables related to the two different food categories (Padulo et al., 2018), experimental stimuli were initially presented on a screen without any time restriction. Participants had to rate the frequency of consumption of each stimulus on a 1–6 Likert scale (1 = Never, 6 = several times), the appetibility (1 = not appetizing at all, 6 = very appetizing), and irresistibility (1 = not irresistible at all, 6 = very irresistible). The between-group comparisons high- vs. low-calorie food within all these three variables did not yield any significant result (two samples independent t-test $p > .05$).

2.2. Stimuli

Target stimuli were obtained from the Food-pics Database (Blechert et al., 2019). We selected six high-calorie (cashews nuts, pizza, donut, biscuits, pistachios, almonds) and six low-calorie (i.e., cucumber, mixed vegetables, white grapes, green beans, mushrooms, mashed potatoes) stimuli and we turned them into the same frame (circular). To control binocular stability, stimuli were superimposed onto an image of a plate as a contour. Even if already equated from the Database, we extracted low-level features of our stimuli such as brightness, contrast and spatial frequency and we performed an 1-way ANOVA to test for differences among stimuli values. Stimuli low-level features were comparable in each domain (see Supplementary Materials for a description of low-level stimuli features and analysis). The experiment was created with MATLAB (Release 2021b) and Psychtoolbox (Brainard, 1997) and stimuli were presented on a BenQ Monitor (1.920 × 1.080 pixels resolution, 120 Hz, 24″) located 57 cm forehead. Participants' head was placed on a home-made chinrest with a built-in stereoscope and was individually adjusted in order to provide stable binocular vision.

2.3. Experiment 1 (bCFS)

2.3.1. Procedure

Here we assessed whether and how hunger and calorie content affected the time of the access to visual awareness of food stimuli.

The target food stimulus was presented to one eye, while a dynamic high-contrast Mondrian-pattern mask was presented to the other. Both, the stimulus (3.3° x 3.3°) and the mask (9.5°), were presented inside a fusion square (9.5° x 9.5°, one per eye, each at 5.1° from the center) that was created with noise-pixels (width 0.2°). The background screen was black, while the area of the square was white with a black fixation-cross in the center. In each trial, the target was displayed by decreasing its transparency from 100 % to 0 % during the first second of trial and presented at the top or the bottom of the square with a random horizontal jitter. Simultaneously, the transparency of the mask was linearly increased from 0 % to 100 % within 7 s (starting after the first second of trial). Instructions were given both written and verbally.Participants had to keep their eyes fixed on the fixation cross, avoid active target searching and eye-blinking orclosing of the one eye. They were also required to localize as fast and accurately as possible the target position (top or bottom of the fusion square). The response was given by pressing the corresponding keyboard arrows (i.e., top-position: up arrow key, bottom-position: down arrow key) even if they only had a strong feeling that something more than the mask was present, in order to prevent conscious perception. The trial ended with the localization response or after 8 s (with 1 s of ITI). After eight practice trials, the experiment started. Within each of the two conditions, stimuli were randomly administered 36 times to the right eye in a top position, 36 times to the right eye in a bottom position, 36 times to the left eye in a top position, and 36 times to the left eye in a bottom position for a total of 144 trials each condition. The two conditions were administered to each participant in a randomized order for a total of 288 trials. After 96 and 192 trials, a small break was made (see Fig. 1 for time course of a trial and stimuli).

2.4. Statistical analysis

No participants reported instable binocular perception or accuracy lower than 90 %. Trials suggesting absence of suppression (with response time lower than 300 ms; 3.12 % of the trials) and trials with no response were not considered, whereas outliers (± 2.5 SD from the sample mean; 0.2 %) were substituted with the sample mean. Then, for each of the two conditions, mean response times for corrected responses only were calculated, and then log-transformed to account for a not normal distribution of the data (Shapiro Wilks < 0.05). A 2 × 2 repeated measures ANOVA was then conducted with Statistica 12 (StatSoft) with the factors hunger (hungry group, satiated group) and calorie content (low, high).

To explore the potential relationship between individual traits of eating/bodily attitudes and conscious access, we performed a series of Spearman correlations between the questionnaires scores obtained before the experimental session and the bCFS measure.

3. Results

The repeated measures ANOVA revealed a main effect of calorie ($F_{(1, 28)} = 32.68$, $p < .0001$, $\eta_p^2 = 0.54$) with faster responses for high (mean = 0.34, SE = ± 0.03) than for low (mean = 0.38, SE = ± 0.03) calorie food. Furthermore, the interaction group x calorie resulted to be significant ($F_{(1, 28)} = 6.27$, $p = .018$, $\eta_p^2 = 0.18$) and a post hoc test with Bonferroni correction revealed that the only significant comparison ($p < .001$) was observed in the satiated group, being faster in responding to high-calorie (mean = 0.34, SE = ± 0.04) than to low-calorie (mean = 0.40, SE = ± 0.44) food (see Fig. 2). No significant Spearman correlation was found. Observed statistical power (with alpha = 0.05) resulted to be 99 % for the main effect, and 67 % for the interaction.

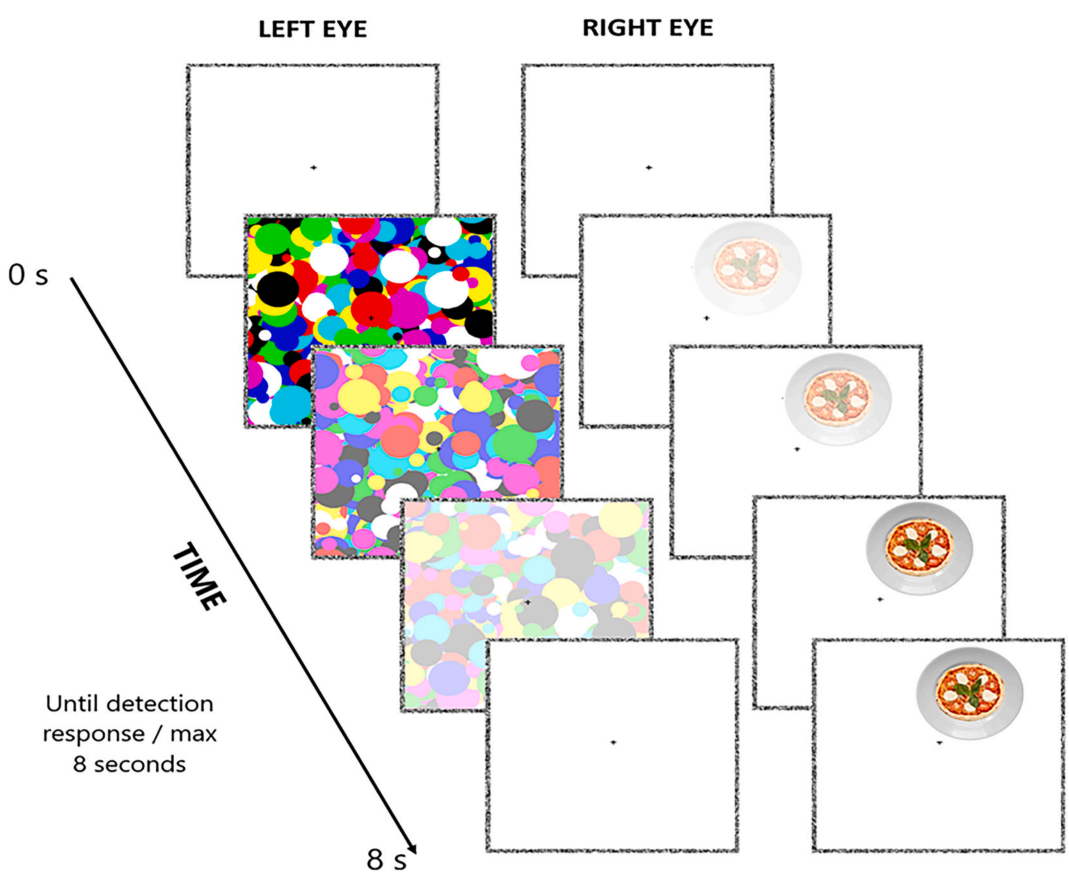

Fig. 1. Schematic representation of the bCFS trial. After 1 s of inter-trial-interval, a high-contrast mask updating at a frequency of 10 Hz is shown to one eye, and its transparency was increased from 0 to 100 % within 1–7 s after the end of the ITI. The target is shown to the other eye, and its transparency is decreased from 100 to 0 % within the first second of trial. Each trial lasted for a maximum of 8 s or until response (top-arrow, top location; bottom-arrow, bot location) once participants detected even a part of the target breaking the suppression, pressing the corresponding arrow as fast as possible.

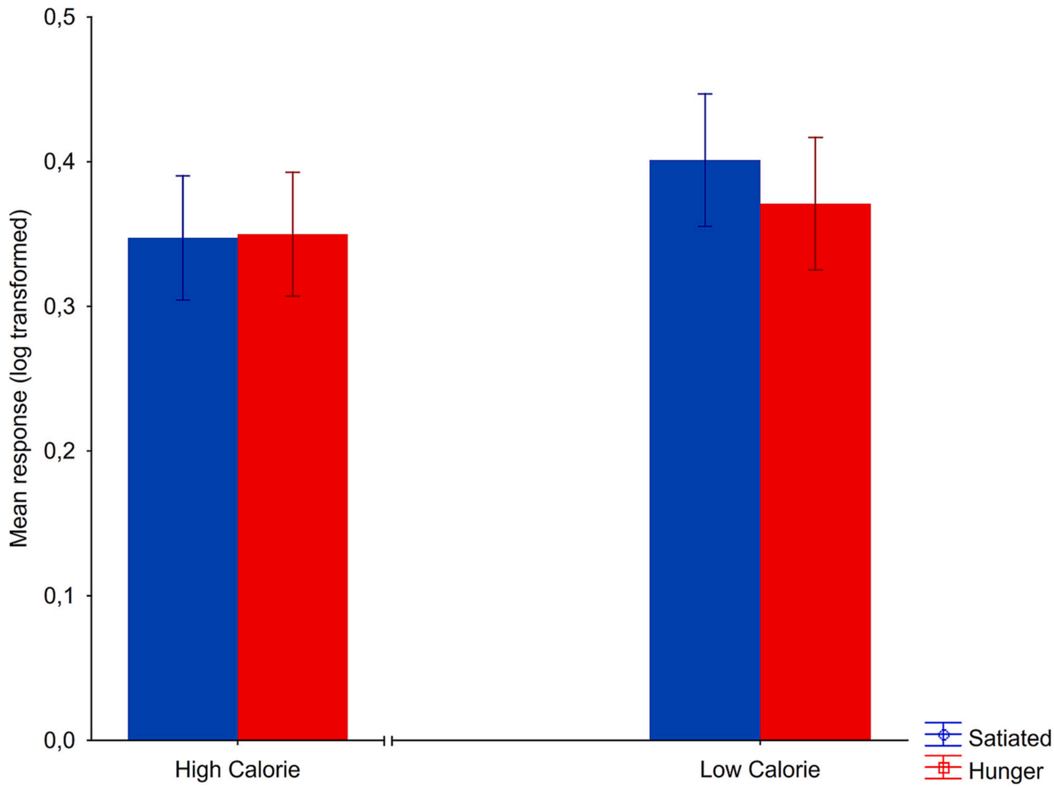

Fig. 2. Results of Experiment 1. Mean log-transformed response time as a function of calories and hunger state (and SE), reflecting the suppression time of the targets. $*p < .05$, $**p < .01$, $***p < .001$.

4. Discussion

In the current experiment, we investigated the role of the calorie content and hunger on visual awareness of food stimuli, by examining the time of conscious access through the breaking-Continuous Flash Suppression paradigm. We compared low vs. high-calorie food in participants in two different homeostatic states, namely hungry or satiated groups. Our results showed that, high-calorie food access faster visual awareness, but the effect was mainly driven by the satiated group. No significant correlation was found.

We have already argued that the breaking-Continuous Flash Suppression (bCFS) paradigm peculiarity is measuring the timing for the transition from unconscious to conscious visual processing of a given stimulus category. The idea is that faster responses of one stimulus category over another, reflect prioritization for awareness. Notably, the existing bCFS literature has already demonstrated that even semantic features can be processed before consciousness. This mechanism is evident in various domains, including the meaning of words (Yang & Yeh, 2011), the emotional valence of faces (Capitao et al., 2014; Zhan et al., 2015) (Lanfranco, Rabagliati, & Carmel, 2023), and even with food (as compared to non-food) images (Karremans et al., 2006; Sato et al., 2017) (for a comprehensive review on high-level effects in bCFS, see (Stein, 2019). Similarly, there is evidence showing that also a specific homeostatic state can modulate unconscious responses to nutrients (Karremans et al., 2006; Sato et al., 2017). In line with these considerations, it is not surprising to expect that calorie content (i.e., a specific semantic feature of the visual stimulus) and hunger (i.e., a physiological state) modulate food stimuli processing before visual awareness. The main effect of calorie content we report here (i.e., a high-calorie food unconscious advantage) basically replicates the findings of a previous bCFS study (Lee et al., 2022). Interestingly, that study also explored the possible relationship between calories and hunger. Although, the results showed no significant correlation between thesubjective hunger (quantified on a Likert scale) and the time required by the high- /low-calorie food to overcome the mask suppression. Differently to that study, here we adopted a between subjects' design in which our sample was divided into two, distinct groups (i.e., hunger and satiated). Additionally, the criteria we employed to obtain the two groups were very stringent and conservative (see materials and methods). Meaning that being or not being fasted, should have been confirmed by the subjective feeling of hunger. Contrary to the results of that study, we reported that hunger interacted with calorie content. Specifically, the advantage for high-calorie food was mainly driven by the satiated group. In other words, although high-calorie food gained a faster access to awareness in both groups, the statistically significance of this difference, was observed exclusively in satiated participants. How could we explain these results? It is well-known that human species have an innate preference for energy dense and palatable foods (Bleich et al., 2015; Drewnowski & Rock, 1995) (essentially high-calorie food) because of their intrinsic evolutionary and hedonic value. Hence, we suggest that the unconscious prioritization of high-calorie food would represent the default condition of the visual system, inherently 'tuned' towards this category of nutrients. Such a state would strongly facilitate the subsequent higher-order processes related to visual processing of the most relevant nutrients. Furthermore, our data show that food deprivation reduced such unconscious advantage, as responses to low-calorie food were speeded up in such way that they were not significantly different from high-calorie food responses. In evolutionary terms, hunger is a condition of homeostatic emergency where in the need of energy intake is so high, that the available items can be insufficient, difficult to obtain (e.g., in the far space) and problematic to detect (e.g., in presence of several visual stimuli). To maximize the chances to survive, the visual system should adapt itself into a less conservative prioritization condition. Consequently, the visual system would shift its unconscious prioritization default state, ensuring that all type of food stimuli entail equal prioritization. Therefore such state would be reached by increasing the relevance of low-calorie stimuli.

4.1. Experiment 2 (BR)

4.1.1. Procedure

Here we evaluated whether and how hunger and calorie content affected the time of dominance in visual awareness of food stimuli.

A high-caloristimulus was shown to the one eye, whereas a low-calorie stimulus was shown to the other (counterbalancing the eye-calorie pairs) for 60 s. Stimuli were displayed within squared frames (7.2° × 7.2°) on a black background, made of white and black pixels (width 0.2°) at 5° from the center (one on the left, one on the right), a red central fixation-cross was presented in the center. After the instructions (written and verbal form), four practice trials were administered. Participants had to keep the eyes on the fixation-cross avoiding active searching, eye-blinking, or closing one eye. They had to press the left arrow if they perceived more than the 50 % of the high-calorie stimulus (i.e., high-calorie predominance), the right arrow if they perceived more than the 50 % of the low-calorie stimulus (i.e., low-calorie predominance), the up arrow if no predominance was perceived. Participants had to report their perception each time it changed (between the three above mentioned conditions), with the corresponding arrow. Within each condition, stimuli were randomly administered 12 times to the left eye, 12 times to the right (24 trials in total). A 30 s break for eye resting, was given after each trial and longer (60 s) one was given after 12 trials (see Fig. 3 for time course of a trial and stimuli).

4.2. Statistical analysis

No participants reported extremely short dominance time instable for targets and/or reported instable binocular perception. Mean response times for both high-calorie and low-calorie stimuli were computed (data were normally distributed at a Shapiro-Wilks test, $p >$ .05), while mixed dominance times were not considered for the analysis. On such dependent variables, we employed Statistica (StatSoft) to run a 2 × 2 repeated measures ANOVA with the factors hunger (hungry group, satiated group) and calorie content (low, high). As for Experiment 1, we ran a series of Spearman correlations between the predominance performances and the other measures.

5. Results

The repeated-measures ANOVA on targets revealed a significant main effect of calorie ($F_{(1,\ 28)} = 92.60$, $p < .0001$, $\eta_p^2 = 0.77$). High-calorie foods(mean = 29.22, SE = ± 29.93) were perceived for a longer time than low-calorie (mean = 19.95, SE = ± 20.68) foods (see Fig. 4). Correlations revealed that responses to high-calorie food were positively correlated to the MAIA NW scale ($r = 0.46$, $p = .011$), and responses to low-calorie food were positively correlated to the Bulimia

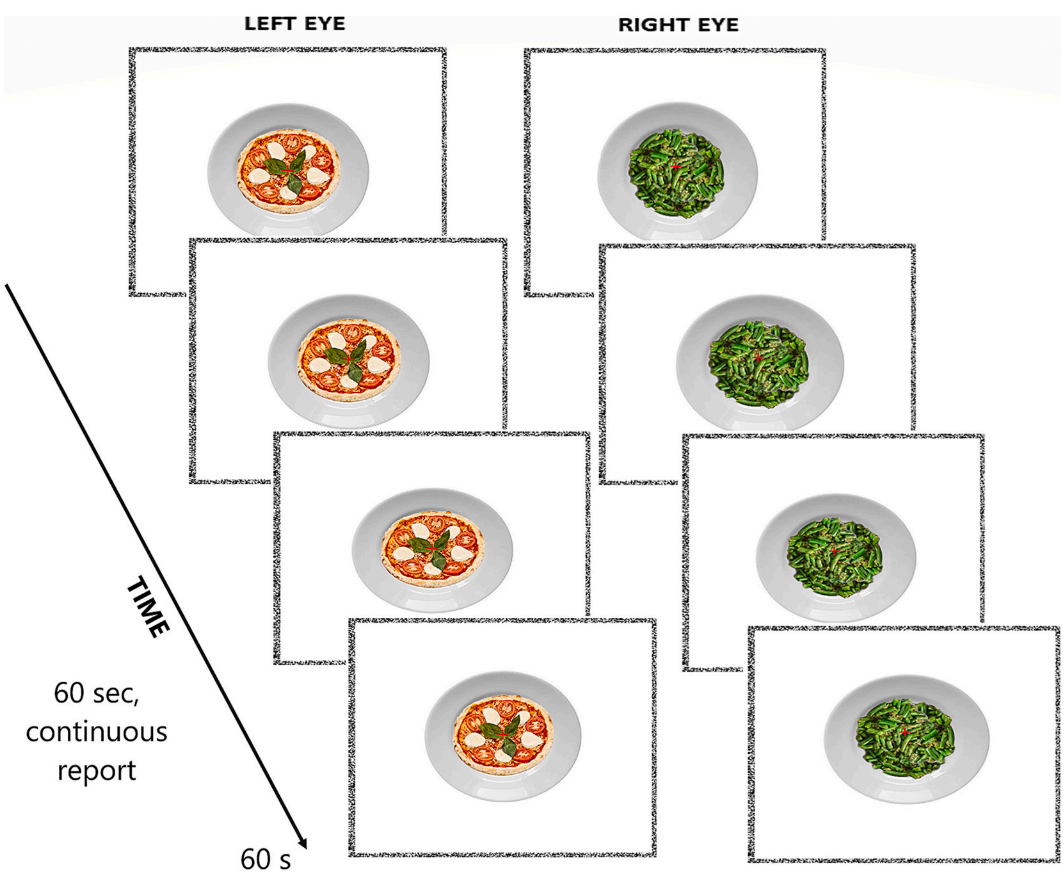

Fig. 3. Schematic representation of the Binocular Rivalry trial. Participants were exposed for 60 s to binocular presentation of a high-calorie stimulus in one eye, and a low-calorie to the other. They had to report their dominant percept and the changes over time, by pressing the correspondent arrow (left-arrow, high-calorie predominance; right-arrow, low-calorie predominance; top-arrow, not a predominance). After each trial there was 30 s of eye-rest.

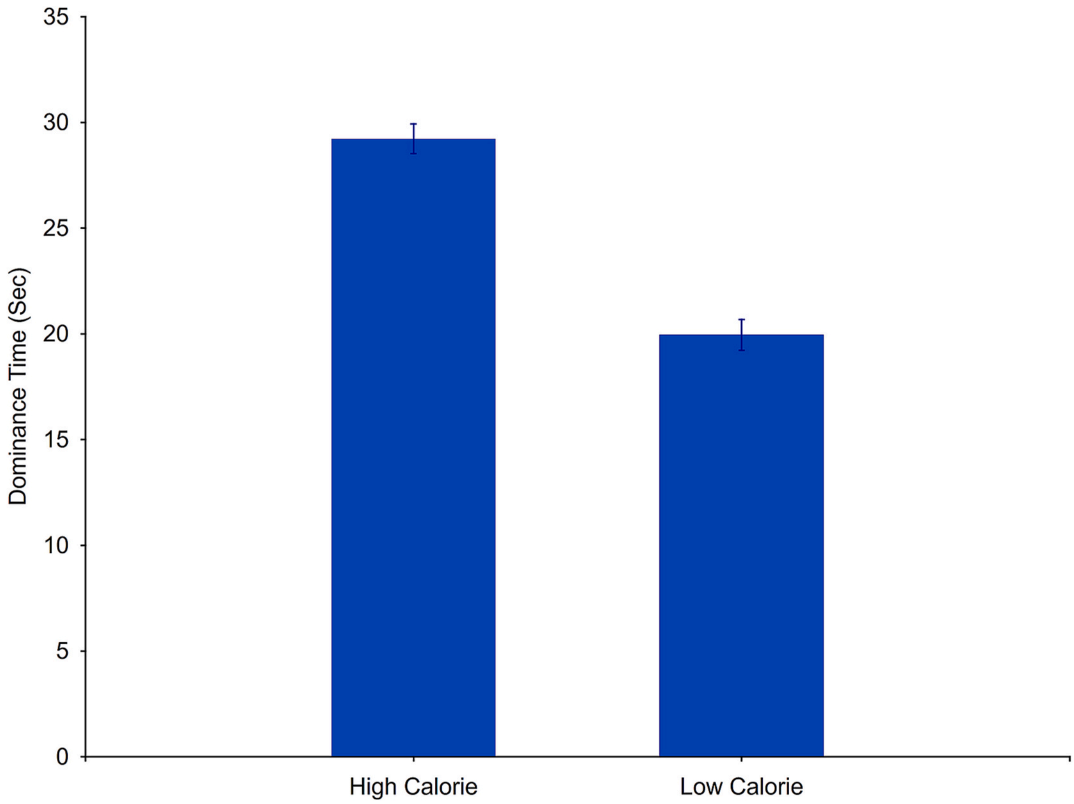

Fig. 4. Results of Experiment 2. Mean predominance times (and SE) for each condition. *p < .05, **p < .01, ***p < .001.

($r = 0.42$, $p = .021$) and Body Dissatisfaction scales ($r = 0.41$, $p = .026$) of the EDI-3. Observed statistical power (alpha = 0.05) resulted to be 100 % for the main effect of calories.

6. Discussion

Here, we investigated the role of calorie content and hunger on visual awareness of food stimuli. We focused on the perceptual dominance by means of the BR paradigm. We aimed to compare low vs. high-calorie food in hungry and satiated participants and our results demontrated that high-calorie food dominated visual awareness for a longer conscious period, regardless the hunger state. Moreover, the perceptual dominance for high-calorie food was positively correlated to emotional insensibility to negative feelings, whereas the one for low-calorie food was positively correlated to bingeing thoughts and to body dissatisfaction.

It is important to re-emphasize that in BR, the stimulus category that dominates perceptual experience for a longer time is thought to be, at least to some extent, consciously more relevant. Importantly, the most recent models of rivalry underline that for such effect to occur, visual attention is barely required (Li et al., 2017). Broadly speaking, existing literature has demonstrated that higher order semantic features can modulate the dominance time of visual stimuli. This occurs, for instance, with the meaning of words, with (un)possible objects, and reward associations (Marx & Einhauser, 2015). In a similar vein, hunger is known to enhance conscious perception of food items (di Pellegrino et al., 2011; Mogg et al., 1998; Piech et al., 2010). Hence, as for the time of access, it is not trivial to predict that the semantic content of the stimulus (i.e., calorie content) and the physiological state (i.e., hunger) can jointly affect the perceptual dominance of food images. A previous BR study found that participants had a longer dominance time for pictures of food as compared to non-food control images, regardless of the homeostatic state of hunger or satiety (Weng et al., 2019). However, no study hitherto has investigated the role of hunger and calorie content on perceptual dominance at the same time. The main effect of calorie content we report here (i.e., a high-calorie food perceptual dominance) seems to be consistent with a variety of electrophysiological (Potthoff & Schienle, 2020; Sarlo et al., 2013) and eye-tracking (Manippa et al., 2019; Motoki et al., 2018) studies which repeatedly reported that images of food, particularly those with the highest calorie content, attract visual attention. Additionally, these attentional circuits support visual sampling of the environment by interacting with motivational and emotional systems (Spence et al., 2016). Consistently, it has been demonstrated that high-calories are significantly associated to reward which, in turn, is known to act upon visual attention (Pessoa, 2015). Interestingly, the correlation analysis showed that the more high-calorie food dominated conscious perception, the higher was the score to Not-Worrying scale of MAIA. This scale is an index of participants' ability to not become emotionally reactive to uncomfortable internal sensations, and its reduction is associated to the perceived feelings of being fat (Pink et al., 2021). Hence, it might appear reasonable a link between the insensitivity to negative sensations and the visual dominance of high-calorie food which are potentially related to triggering feelings of satiety. The other significant correlations showed that the more low-calorie food dominated perception, the higher was the score in the Bulimia and Body Dissatisfaction scales of the EDI-3. Binge-eating is characterized by a sense of losing control during eating and purging behaviors, particularly towards highly palatable foods (Shank et al., 2015), whereas body dissatisfaction can be defined as the negative attitudes towards one's own body and it is often associated to bias towards high calorie food (Xie et al., 2023). In both cases, the fear of gaining weight is an important feature (Cash et al., 1990; Wiederman & Pryor, 2000). We speculate that our results could represent an indirect consequence of a top-down cognitive effort to control the drive towards high-calorie food stimuli, so to reduce the negative feelings and worry. This might lead to a paradoxical ‘hyperattention’ to low-calorie food (i.e., the perceptual dominance we report here). Alternatively, people with binge-eating or body dissatisfaction attitudes may exhibit attentional biases towards food stimuli (regardless the calorie content), as strategy to monitor food exposure and maintain dietary restrictions (Blechert et al., 2011). This, in turn, could potentially lead to increase visual attention towards low-calorie stimuli.

With respect to the apparent lack of an effect of hunger is in contrast to the studies showing that such physiological state enhance attention towards visually presented food stimuli (di Pellegrino et al., 2011; Mogg et al., 1998; Piech et al., 2010). However, it is worth noting that those studies compared food vs non-food stimuli rather than the calorie content. We speculate that the absence of an effect of hunger might be attributed to the possibility that a conscious attentional bias towards high-calorie food would represent a higher-order useful mechanism, independent form the semantic content. Indeed, food evaluation based on visual information before ingestion represents the first perceptual stage at which nutritional choices are made by the individuals. However, the process continues with gustation, which is a multisensory process that allows for the selection of some nutrients and rejection of others. Here, it is well known that hunger can have a strong impact (Hanci & Altun, 2016). Alternatively, it is important to note that in our paradigm the high- and low- calorie stimuli were in direct competition with each other for conscious representation in visual awareness, rather than competing for awareness per se with a noisy mask such as in bCFS. Thus, it is possible that, in a competing scenario, the attentional system might still be more oriented to prioritize the most palatable food in both the homeostatic states.

7. General discussion

Summarizing, our results show that high-, as compared to low-calorie food, was prioritized in the access to consciousness, mostly in satiated participants. Moreover, it dominated visual perception longer, regardless hunger. We argue that in normal circumstances, this unconscious advantage would represent the default state of the visual system biased towards more energy-dense food. However, such default state is lost in condition of nutritional 'emergency' in order to enhance the detection and consumption of any food category as an adaptive evolutionary strategy. The conscious advantage would represent a higher-order attentional bias useful for the detection of more nutrient-dense food in the environment. Moreover, this study supports the theoretical framework that concerns perception as an active construct that can be influenced by homeostatic states and top-down processing.

Before concluding, we must acknowledge some limitations, as well as potential future directions. A first problem regards the fact that low-level features, known to have role in unconscious processing (Gray et al., 2013; Stein & Sterzer, 2012), could have had an impact on our results. Indeed, some high-level effects found in bCFS have been shown to rely on low-, rather than high-, level features (e.g., emotional processing (Gomes et al., 2018; Lanfranco, Rabagliati, & Carmel, 2023). Thus, equating low-level stimuli features is extremely important in order to test for high-level effects on visual awareness. Since high- and low-calorie stimuli might entail intrinsic differences, our stimuli were selected under rigorous experimental rules and were equated in brightness, spatial frequency and contrast (see the method section). Despite these clear-cut arguments, one might still argue that color, as crucial intrinsic feature for food stimuli processing (Spence et al., 2010), could have had an impact. However, it is worth considering that brightness itself is expressed as a function of RGB values. Furthermore, such low-level feature is not likely to explain the effect of hunger on calorie perception (the only change was the homeostatic state of the observers, not the low-level stimuli features), and it seems more reasonable to hypothesize a link between hunger and calorie content. A second critical point is related to the fact that bCFS entails some limits in assessing unconscious processing, as detection threshold can be affected by subjective decision criteria for visual awareness that might entail partial conscious identification of stimuli, without purely isolating early unconscious processing. With respect to future studies, non-competing BR studies could be useful to assess hunger effects on visual dominance with respect to caloric content, and it would be worth of further investigation whether and how the variety of variables underpinning feeding behavior affect the emergence into visual (and non-visual) awareness of food stimuli.

Fundings

This work was supported by the Ministry of Education, University and Research (PIA_RILO_19_01).

CRediT authorship contribution statement

Tommaso Ciorli: Writing – review & editing, Writing – original draft, Formal analysis, Conceptualization. **Myrto Dimakopoulou:** Writing – review & editing, Supervision, Methodology, Conceptualization. **Leonardo Trombetti:** Visualization, Supervision, Investigation. **Federica Gini:** Software, Resources, Project administration. **Lorenzo Pia:** Writing – review & editing, Writing – original draft, Investigation, Funding acquisition, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.actpsy.2024.104192.

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