The Habituation-Dishabituation ERP Responses to Repeated Visual Food Cues

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***Abstract*—Existing research indicates that human salivary responses habituate to repeated food cues. This study examines the neurophysiological dynamics of within-session habituation and dishabituation to high/low-calorie food and non-food images, with Event-Related Potentials (ERPs) measured as participants viewed these images, including distractors. The analysis showed significant habituation (decreased response) and dishabituation (response recovery) in the parietal area, particularly within the 160-290 ms time window. The non-food image exhibited a linear decrease with repetition, and responses recovered when novel stimuli were introduced. High and low calorie images did not show significant linear habituation, maintaining sustained attention and motivation instead. However, both food image types displayed a recovery response during the dishabituation phase. The ERP results also indicated that food images have a slower rate of decline compared to non-food images. In conclusion, our ERP study demonstrated that a habituation-like mechanism influences attention in response to repeated non-food images, while food images had minimal impact. Food images, with their higher reward value, led to prolonged attention and hindered habituation. These reduced neural attentional habituation and a slower rate of habituation to food stimuli could have negative health consequences. Furthermore, the dishabituation effect observed across all images underscores that the habituation phenomena are not simply due to mental fatigue.**

***Index Terms*—Electroencephalogram (EEG) Signal Processing, Event-Related Potential (ERP), Food Image Repetition, Habituation, Dishabituation**

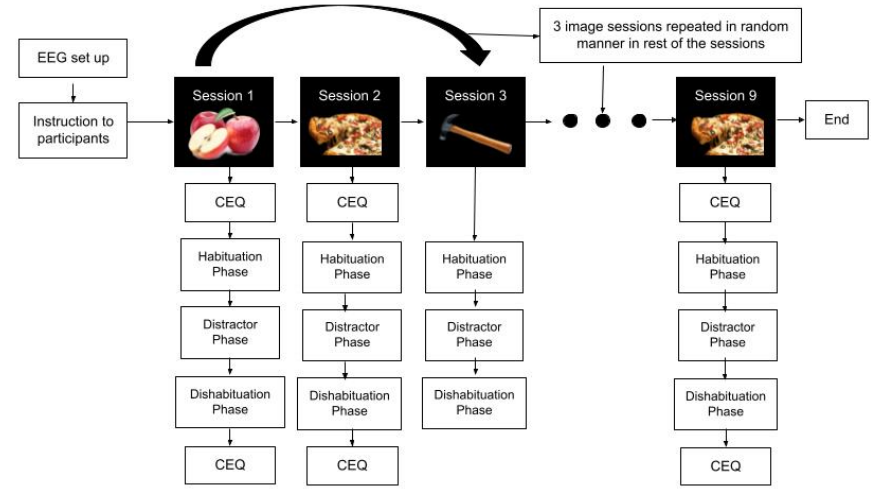
I. Introduction

The global prevalence of obesity is on the rise, resulting in long-term health complications such as diabetes and heart disease [1]. External sensory stimuli play a significant role in individual eating preferences and the pleasure derived from eating [2]. These stimuli affect dietary preferences and the quantity of food consumed. Habituation, which is characterised by a reduction in physiological and behavioural responses to food, can result from repeated exposure to visual, olfactory, or gustatory stimuli during eating [3]. A slower rate of habituation is associated with greater food intake and overeating. Research indicates that obese children and adults experience slower habituation rates compared to their non-obese counterparts [4], suggesting that slower habituation contributes to increased food consumption in overweight individuals. Therefore, regulating habituation could serve as an intervention model for eating disorders and obesity [3].

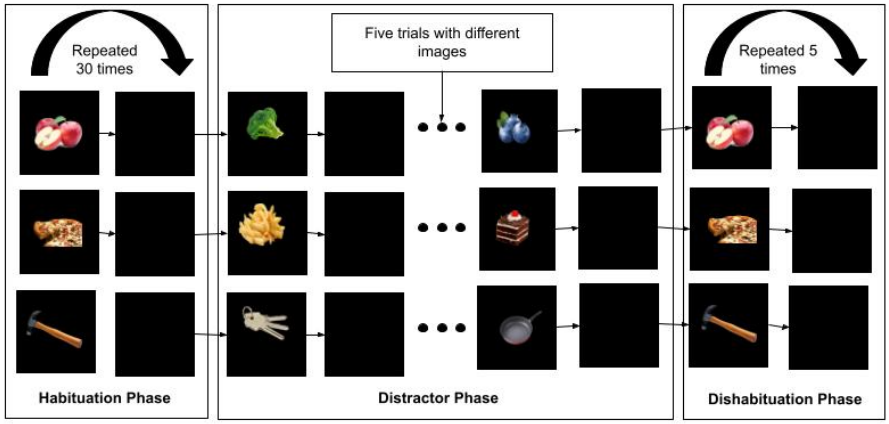
Moreover, when habituation occurs, the introduction of a new external stimulus (distractor) can lead to dishabituation, which is the recovery of response to the habituated food stimulus [5]. This phenomenon demonstrates that habituation is the underlying mechanism for the observed decrease in responding, distinguishing it from receptor or effector fatigue [6]. The unique ability of a dishabituator to restore responses to a habituated stimulus is specific to habituation theory. Thus, habituation serves as a model for eating disorders and provides a framework to understand how sensory stimuli influence food choice and the amount consumed.

Research on food habituation has observed decreases in response through various methods, such as salivation responses in children and adults [7], [8], electrophysiology through facial muscle responses in adults [9], and motivated behaviour/reinforcing responses to obtain food in both adults and children [3], [10]. Even motivated responses to food show habituation to repeated visual stimuli without actual food consumption [11]. Each of these studies demonstrated a decrease in response to repeated presentations of the same food, followed by a recovery of responses when a different food was provided. However, these measures are not practical for interventions aimed at examining food habituation behaviour. This study investigates how the brain responds to repeated presentations of food and non-food visual stimuli and how these responses are modulated by introducing novel stimuli neurophysiologically within a session. Using ERP, the neural correlates of habituation and dishabituation were measured in this context.

Studies using ERPs have demonstrated strong neural responses to food-related stimuli, with higher amplitudes observed for food cues than non-food stimuli [12]. Initial sensory or visual attention to food cues may explain whether these cues receive higher-order attentional processing, influencing eating patterns. Research indicates that initial sensory components like P2, N2, and anterior negativity exhibit greater amplitudes for food stimuli than neutral stimuli [13]–[15]. Additionally, food stimuli with intense sensory qualities or significant health implications show increased P1, N1, and P2 amplitudes starting around 150 ms [16], [17]. In the early ERP window ($\sim$150–200 ms), studies have found greater negative amplitude (N2) for chocolate images compared to neutral images in individuals with binge eating behaviour [18]. This distinction



(a)



(b)

Fig. 1: (a) Overall experimental design, EEG - Electroencephalogram, CEQ - Craving Experience Questionnaire (participants record their current craving intensity); (b) Habituation, Distractor, and Dishabituation phases for each image category: low-caloric, high-caloric, and non-food. All images were displayed for 4 seconds, followed by a 2-second inter-stimulus interval (ISI) featuring a blank screen.

in early ERP components and late positive potential (LPP) modulation suggests the motivational significance of external stimuli, likely mediated by the activation of corticolimbic appetitive and defensive systems, supporting individuals' perception and action [19].

The primary objective of this study was to determine whether attention and motivational responses, as measured by ERP, differ with repeated presentations of high-caloric, low-caloric, and non-food images and whether these responses exhibit a habituation process within the session. We hypothesised that food images would elicit greater motivation than non-food images and that high-caloric food images would elicit greater motivation than low-caloric food images. Furthermore, we expected all images to exhibit the habituation process. The secondary objective was to assess the reliability of slower habituation rates during the habituation phase for high-caloric, low-caloric, and non-food images. Our hypothesis was that food images, particularly high-caloric ones, would exhibit slower habituation rates than non-food images. The third objective was to determine whether introducing novel stimuli would result in dishabituation, with the hypothesis that both food and non-food images would show a recovery of response.

II. Methodology

A. Participants

Thirteen participants (eight females and five males) were recruited via campus announcements. Participants' ages ranged between 24 and 39 years (mean = 27.84±4.38). Liking of apple and pizza was evaluated using a six-point Likert scale (0 = low; 5 = high), and only participants who scored 3 or above for both pizza and apple were included in the experiment. The main exclusion criterion was neurological or current mental disorders (e.g., eating disorders). Body mass index (BMI) ranged from 19.72 to 28.67 kg/m^2 (mean = 24.54±2.80), with 7 participants (4 female and 3 male) being overweight or obese. One overweight female participant's data was excluded

from the analysis due to excessive noise in the data, so the analysis were performed on 12 participants. The study was approved by the Faculty of Sciences, Research Ethics Committee at the University of Kent. Prior to participation, all participants provided written informed consent for their involvement in the experiment. Participation was voluntary without any payment.

B. Experimental Design and Procedure

Participants were shown three images on a monitor one meter away: an apple (low-calorie), a pizza (high-calorie), and a hammer (non-food). They participated in nine sessions in one day. In each session, one image from the categories was randomly displayed for four seconds, followed by a two-second inter-stimulus interval (ISI) showing a blank screen. This was repeated 30 times per session (habituation phase), followed by a distractor phase of five trials with various session-related images, and ending with five trials of the initial habituation stimuli (dishabituation phase), totalling 40 trials per session —(refer to Figure 1). Food cravings were measured at the start and end of food-related sessions using the Craving Experience Questionnaire (CEQ).

All participants gave written informed consent and underwent a screening to ensure eligibility. They were advised to eat a substantial breakfast and avoid eating three hours before the sessions to standardise responses and control hunger impacts [20]. Experiments began at noon. Upon arrival, participants filled out the Dutch Eating Behaviour Questionnaire, were equipped with EEG electrodes, and were briefed about the experiment. They underwent a test trial upon request and then proceeded with viewing images, each session lasting around five minutes while EEG data were collected.

C. EEG Recording and Data Processing

For this study, EEG data was captured using Neuroelectric's StarStim device with 32 electrodes, following the 10-10 system placement, and sampled at 500 Hz. The reference and ground were established using CMS and DRL electrodes positioned on an ear clip. Data analysis was performed using Matlab (R2023a) with EEGLAB (v2023.1) and Fieldtrip (v20231220). Preprocessing included high-pass filtering at 0.5 Hz and low-pass filtering at 30 Hz. Bad channels were identified, removed, and interpolated. ICA was conducted to remove artefacts related to eye movements, heartbeats, and other noise, focusing on components with a probabilistic score over 75%. Data were then segmented into epochs from -100 ms pre-stimulus to 1000 ms post-stimulus for detailed analysis. The study analysed data from 40 trials across 12 participants, grouped by image category (high-caloric, low-caloric, non-food) and averaged over time. Trials were divided into eight groups of five, with each undergoing a cluster-based permutation test to assess habituation and dishabituation effects, detailed in Table I. This setup facilitated the examination of EEG signal changes over time, enabling comparisons across different phases of the study: habituation, distractor, and dishabituation.

TABLE I: Trial groups and their corresponding trial ranges were defined as follows: 40 trials were divided into 8 groups, each containing 5 trials, for three images across three sessions.

Group Name	Trial range	Phase type
Trial Group 1	1-5	Habituation
Trial Group 2	6-10	Habituation
Trial Group 3	11-15	Habituation
Trial Group 4	16-20	Habituation
Trial Group 5	21-25	Habituation
Trial Group 6	26-30	Habituation (pre-distractor trial group)
Trial Group 7	31-35	Distractor
Trial Group 8	36-40	Dishabituation

III. Statistical Assessment

Significant main effects and interactions of ERP responses to three images during the first 1000 ms after cue onset were examined. The habituation and dishabituation effects within-session for the three images were investigated using a mass-univariate analysis with a cluster-based statistical approach. Specifically, EEGLAB and FieldTrip plugins were used to conduct a non-parametric cluster-based permutation test with Monte Carlo randomisation [21]. The methodology was based on FieldTrip documentation [22] and relevant academic studies [23], [24]. To avoid assuming a normal distribution, a non-parametric test was employed. This approach assumes that actual neural activity generates signal changes over contiguous time points.

Random permutation testing (run 1,000 times) for each subject-specific trial group in each condition was utilised to generate a reference distribution for the mean cluster magnitude. To assess the hypothesised overall habituation and dishabituation effect, trial groups were analysed with the condition: trial group 1 $>$ trial group 2 $>$ trial group 3 $>$ trial group 4 $>$ trial group 5 $>$ trial group 6 $<$ trial group 7 $>$ trial group 8. The adopted test statistic (t-value) was obtained based on linear regression analysis for dependent samples using the *ft_statfun_depsamplesregrT* function in FieldTrip. Clusters in the observed data were considered significant if their magnitude exceeded the 2.5th and 97.5th percentile thresholds (5% significance, two-tailed test).

In addition to the above analysis, to assess the hypothesised dishabituation effect alone, an ANOVA test was used with the conditions: pre-distractor phase (trial group 6) $<$ distractor phase (trial group 7) and pre-distractor phase (trial group 6) $<$ dishabituation phase (trial group 8). The adopted test statistic (t-value) was obtained using the *ft_statfun_depsamplesT* function. Clusters in the observed data were considered significant if their magnitude exceeded the 95th percentile thresholds (5% significance, right-tailed test).

IV. Results

Significant main effects and interactions for ERPs were examined across various time windows and regions of interest (ROIs), including the parietal (P7, P3, Pz, P4, P8), frontal (Fp1, Fp2, F7, F3, Fz, F4, F8), central (C3, Cz, C4), temporal (T7, T8), and occipital (O1, Oz, O2) regions. The cluster-based permutation test on the overall effect of habituation

and dishabituation analysis revealed a significant difference between different trial groups for hammer visual stimuli but not for apple and pizza visual stimuli (refer to Figures 2a 2b and 2c). Only hammer images showed significant habituation and dishabituation effects, with the most pronounced differences over the parietal area of the brain.

Figure 2c shows the mean ERP amplitudes for different trial groups plotted over the parietal region for the hammer image. The results revealed statistically significant main effects within the 160-290 ms time window (p-value = 0.001), highlighted in grey. Figure 3a illustrates the peak amplitudes of each trial group and the habituation trend during the habituation phase, while Figure 3b displays the peak amplitudes during the dishabituation phase. This indicates a linear habituation from trial group 1 to 6 and response recovery in the dishabituation phase (trial group 8).

Figures 2a and 2b present the mean ERP amplitudes for different trial groups plotted over the parietal region for low-calorie and high-calorie images, respectively. The results indicate no evidence of the overall habituation and dishabituation effect across trial groups for apple and pizza, with p-values of 0.058 and 0.09, respectively.

Since the apple and pizza images did not show overall significance, significant main effects and interactions were examined for ERPs across various time windows, specifically in the parietal region (P7, P3, Pz, P4, P8) to determine if trial groups in the dishabituation phase showed any significance using ANOVA test. The results reveal that all images exhibit response recovery in the dishabituation phase (p-value < 0.05) (refer to Figure 3b).

Figure 3a displays the linear trends for the low-calorie, high-calorie, and non-food image trial groups 1 to 6 (habituation phase). The slope and intercept values for these three images are provided in Table II. The result indicates that the rate of habituation was faster for non-food images (slope = -0.15) compared to high-calorie (slope = -0.04) and low-calorie images (slope = -0.01).

TABLE II: Habituation rate details for different images.

Image	Slope	Intercept
Apple	-0.01	2.71
Pizza	-0.04	3.04
Hammer	-0.15	2.85

V. Discussion

This study uniquely investigates the impact of habituation and dishabituation on different time windows within a session using repeated presentations of food and non-food images. The goal was to analyse evoked potentials from EEG data for trial groups exposed repeatedly to varied energy-value images, focusing on how repetition affects habituation for high and low-calorie images across six trial groups (1-30 trials).

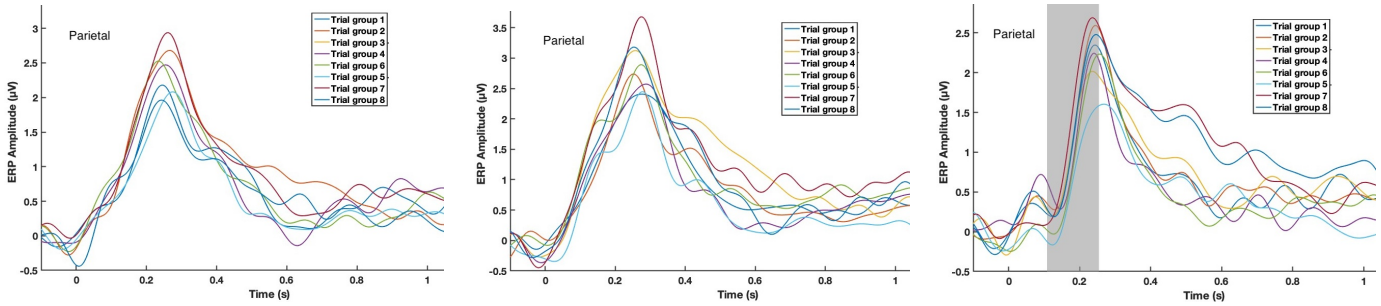
Findings support the hypothesis that changes in response to repeated food presentations indicate habituation, notably with significant effects observed around 160-290 ms for non-food images in parietal brain areas. However, high and low-calorie images did not show significant habituation effects. The non-food images demonstrated a decreasing trend over time, whereas food images did not show the expected decline. The ERP results obtained in this study are comparable to those from previous studies on food habituation observed through salivation responses in children and adults [7], [8], electrophysiology through facial muscle responses in adults [9], and motivating behaviour/reinforcing responses to obtain food in both adults and children [3], [25] (refer figures 2 and 3).

Furthermore, neuroimaging studies have shown that viewing food images activates brain regions associated with taste, reward, and memory [26], [27]. The integration of responses in these areas allows individuals to assess the relevance of the stimulus and, if sufficiently motivated, initiate eating behaviours. Once these behaviours are established, brain responses to food stimuli become habitual [28]. Our data suggest that the habituation of neural responses to food also leads to the habituation of behavioural responses, even without actual food consumption. This implies that engaging with food images continues to draw attentional resources despite previous exposure. These findings support previous ERP research [18], [27] indicating that the repetition of food images represents a high level of motivation, especially when comparing food (low/high caloric) to non-food images. Among food, the high caloric image shows high motivation.

The relationship between habituation rates to food and obesity development was assessed by measuring changes in these rates across six trial groups within a session, analysing motivational ERP responses over time. This study explored how motivation and attention levels adjusted across repeated presentations of food and non-food images, noting the linear trend of decrease visible in Figure II, which signifies habituation. Results indicate that while non-food images clearly demonstrated habituation, food images, especially high-caloric ones, maintained attention longer, suggesting less habituation. Interestingly, low-caloric images showed a slower habituation rate than high-caloric ones, pointing to unexpected nuances that require further exploration. This analysis underscores that food images, due to their higher energy density, tend to keep our attention longer, impacting ERP responses significantly.

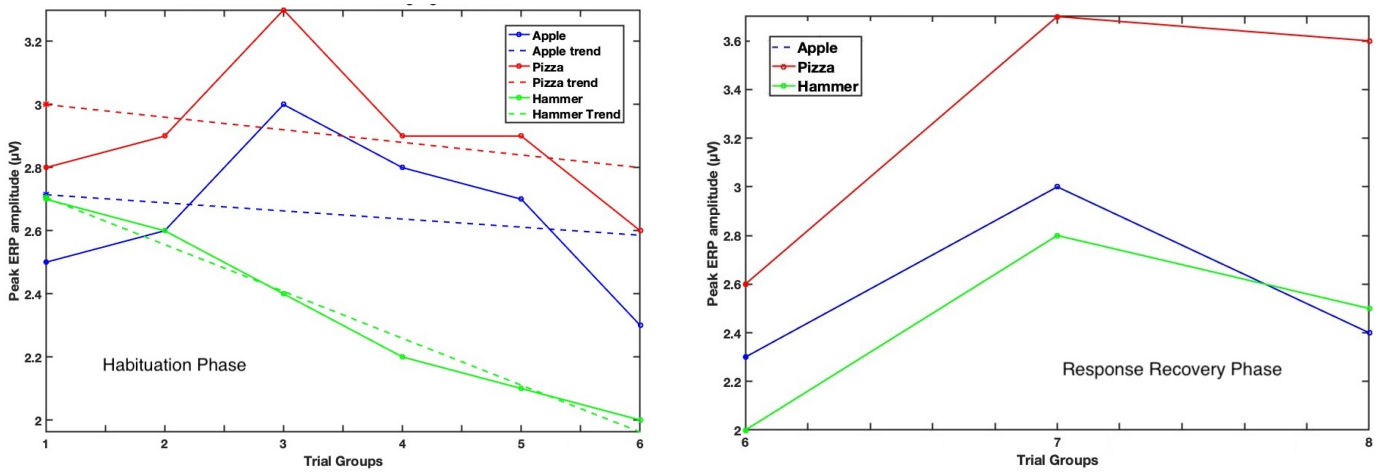
Furthermore, the findings of this study align with previous research indicating that high-caloric foods slow the habituation process and increase energy intake in children [25]. If habituation functions as a mechanism for eating cessation, then a slower rate of habituation (with responses remaining elevated over a longer period) should predict higher caloric intake. This has been demonstrated in studies of motivated behaviour habituation, where diversity reduces the rate of habituation. When a variety of foods is provided frequently, rather than the same item, a greater amount of energy is consumed [25]. Additionally, a slower rate of habituation in motivated eating responses is associated with increased energy intake.

In the third part of the analysis, the influence of presenting novel stimuli (distractor stimuli) on the modulation of different time windows was examined by comparing the pre-distractor trial group (trial group 6) and the dishabituation trial group



(a) Apple (b) Pizza (c) Hammer

Fig. 2: Mean ERP amplitude of different images and trial groups



(a) Habituation phase (b) Response recovery phase includes distractor, dishabituation phase

Fig. 3: (a) Display the peak ERP amplitude and its linear trend for various images and trial groups during the habituation phase, specifically from trial groups 1 to 6. Similarly, (b) illustrates the peak ERP amplitude and its linear trend for different images and trial groups during the dishabituation phase, from trial groups 6 to 8.

(trial group 8) when various food and non-food images were used as distractors. For this, changes in brain response were measured between the pre-distractor and dishabituation trials within a session using motivational ERP responses over time. The results indicate that all three types of images demonstrated dishabituation, or recovery of response when a distraction was introduced. It can be inferred that the presentation of novel stimuli (distractor stimuli) influences brain response, leading to response recovery (dishabituation). This effect was observed across various food and non-food images, evidenced by a greater ERP amplitude in the dishabituation phase compared to the pre-distractor trial (refer to Figure 3b for details).

Existing research presents several experimental arguments supporting the role of dishabituation mechanisms during food intake when a distractor is introduced, whether it is a food [7] or non-food [29] stimulus. Previous studies show that humans habituate to repeated food cues and recover their response when a new food cue is presented, affecting both salivation and motivated responses to food. For example, Epstein et al. [7] investigated salivary habituation to repeated presentations of small amounts of lemon or lime juice, using the alternative juice as the dishabituating stimulus. They found that the dishabituation of salivation and hedonic ratings to the original juice occurred after a new juice was presented. Another study demonstrated that dishabituation can occur when subjects are distracted, such as by watching TV, which increases their response to food intake. Temple et al. [29] found that the group watching continuous television spent more time eating and consumed more energy than the no television and repeated segment groups. These findings support the notion that introducing a distractor can effectively recover habituated responses, consistent with the results observed in this study.

VI. Conclusion

This study evaluated food habituation and dishabituation through repeated visual food stimuli and their rates. Our findings indicate that the habituation effect is observable in the 160-290 ms time range in the parietal regions of the brain for non-food images but not for food images. This discrepancy might be due to sustained attention elicited by food images over time, while non-food images exhibit decreasing attention. This decrease in attention reflects the habituation process and

is more pronounced for non-food images. Additionally, the habituation rate was faster for non-food images than food images in the parietal region (refer to Figure 3a). Interestingly, among the food images, low-calorie items showed a slightly slower habituation than high-calorie items, suggesting that healthier food options also captivate attention longer, potentially leading to overconsumption of even healthy foods.

Moreover, all image types demonstrated dishabituation, signifying that the observed habituation is not merely a result of sensory adaptation, fatigue, or motor responses. These findings align with prior studies on food habituation that measured salivary responses and relied on self-reported data [3]. Additionally, existing research indicates that food variety significantly impacts eating motivation and overall energy intake, with studies showing that diverse food offerings heighten food appeal, particularly in children and adults [5]. This variety often leads to increased caloric intake and might contribute to the higher motivation observed in overweight children toward eating due to varied food options [30], [31].

Thus, an intervention that limits the variety of food in their meal could effectively curb energy intake by limiting overeating and enhancing satiety. Such strategies would alter the food environment and related eating behaviours, reducing the necessity for frequent self-control in food choices and decreasing food intake.

Since this study primarily focused on the effects of repeating the same images without accounting for individual traits, future research will delve into a more detailed analysis of image repetition among high and low BMI groups and different types of eaters (e.g., external, restrained, etc.).

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