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Seeing food fast and slow: Arousing pictures and words have reverse priorities in accessing awareness

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ABSTRACT

Previous studies have shown that stimuli triggering higher arousal (e.g., attractiveness) can access awareness faster than those triggering lower arousal, yet no studies have examined the effect of food calories. Since food brings us energy, satiety, and positive emotions, food stimuli bringing higher arousal would likely have higher priority in accessing awareness over those with lower arousal. We used high-calorie and low-calorie food stimuli as representatives for high and low arousal stimuli, respectively, based on the tight relationship between calorie and arousal. By adopting the breaking continuous flash suppression (b-CFS) paradigm, we had high-calorie and low-calorie food pictures or words presented dichoptically with dynamic Mondrian masks and measured the time for food stimuli to be released from suppression. Our results showed that high-calorie food pictures could access visual awareness faster than low-calorie food pictures (Experiment 1), and the reverse pattern was observed for food words (Experiment 2). We ruled out the possibility of the difference in low-level features (Experiment 3) and post-perceptual response bias (Experiment 4) as the causes for the observed b-CFS time differences. This study revealed the dissociation of the unconscious processing of pictures and words, which may rely on mechanisms related to attentional capture. High-arousing stimuli do not always enjoy priority in accessing visual awareness.

1. Introduction

Food plays a vital role in our daily lives by providing energy. Therefore, food intake is one of the essential human behaviors (Killgore et al., 2003). Statistics show that around 62,000 photos are shared daily under the hashtag #foodporn (Mejova, Abbar, & Haddadi, 2016), suggesting that food information is ubiquitous. Our visual system has also evolved to enhance the efficiency of detecting energy resources, with food being the major one, to increase the chances of survival (Spence, Okajima, Cheok, Petit, & Michel, 2016). Indeed, food affects both our metabolic system and perceptual system.

Emotional information, such as arousal, can influence unconscious processing (Adams, Gray, Garner, & Graf, 2010; Morris, Öhman, & Dolan, 1998; Yang, Zald, & Blake, 2007). For example, more attractive faces and pictures induce higher arousal and enter awareness faster than those with lower attractiveness and arousal (Shang et al., 2020). Namely, high-arousing picture stimuli can dominate conscious experience more than low-arousing ones (Sheth & Pham, 2008). As food usually brings us positive emotion and high arousal (Blechert, Meule, Busch, & Ohla, 2014), a question naturally comes to mind: how is emotional information embedded in food stimuli processed unconsciously?

To this end, we aimed to examine whether food *pictures* with higher calories have priority in entering our visual awareness. Calories and arousal are tightly related (Racine, 2018), as food with higher calories is usually rated as higher arousal than food with lower calories (Blechert et al., 2014). In addition, we aimed to examine whether the corresponding *words* have the opposite result pattern as pictures do for the following reasons.

Pictures and words are processed through different routes in our brains. Previous studies measuring repetitional blindness (RB, the failure to perceive rapidly repeated or similar items) showed that semantic processing in pictures and words undergo different processes at the

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unconscious level (Kanwisher, Yin, & Wojciulik, 1999; Lo & Yeh, 2018): Semantically-related pictures (e.g., airplane and helicopter) demonstrated the RB effect, whereas semantically related words did not. Their results showed faster extraction of semantics in pictures than in words. Additionally, the dual-route hypothesis suggested a direct pathway where the processing of fearful information can bypass the cortical process and goes through the subcortical pathway to the amygdala. This direct pathway is thus fast and automatic. By contrast, the indirect pathway goes through the cortex and reaches the amygdala more slowly (Phelps & LeDoux, 2005, but see Cauchoix & Crouzet, 2013; Pessoa & Adolphs, 2010). It has been shown that emotional faces are processed in the direct pathway (Luo, Holroyd, Jones, Hendler, & Blair, 2007) to the amygdala, whereas emotional words are processed via the occipito-temporal area (i.e., the visual word form area) and then to the amygdala (Cohen et al., 2000; Isenberg et al., 1999); this was further verified by Naccache et al. (2005) with the intracranial neural activity recording in the amygdala. They found that the subliminal emotional words induced activity with a longer latency in the amygdala, in contrast to the short latency elicited by nonlinguistic emotional stimuli (e.g., facial expressions; Luo et al., 2007). Naccache et al. (2005) suggested that there are upstream series of visual word recognition processes (such as lexical access) that should be completed before the extraction of emotional meanings. It is thus likely that emotional words are processed through several cortical areas (i.e., following the indirect pathway), and then to the amygdala, which is also supported by another magnetoencephalogram study (Garolera et al., 2007). It has been shown that emotional words access awareness more slowly than those without emotional information (Prioli & Kahan, 2015; Yang & Yeh, 2011), because negative words (information) detected in the perceptual system interfered with the ongoing lexical process, resulting in the generic slowdown of the lexical access (Larsen, Mercer, Balota, & Strube, 2008). Despite that some studies did not find the unconscious processing of emotional words (e.g., Rabagliati, Robertson, & Carmel, 2018), it should be noted that the language of the stimuli matters (Sheikh, Carreiras, & Soto, 2019): even simplified and traditional Chinese yielded different results (Cheng, Ding, Jiang, Tian, & Yan, 2019). Other studies also showed that neutral words possess a temporal advantage of being processed over arousing words, while the opposite is true for picture stimuli (e.g., Hinojosa, Carretié, Valcárcel, Méndez-Bértolo, & Pozo, 2009; Robinson, Storbeck, Meier, & Kirkeby, 2004). Given that these results suggested that the processing of emotional words proceeds via an indirect pathway whereas the processing of emotional pictures proceeds via a direct pathway to the limbic system, we hypothesized that high-calorie food words that induce higher arousal would likely access awareness more slowly than low-calorie food words, rendering the result opposite to that of food pictures.

A common approach to investigating unconscious processing is the continuous flash suppression (CFS) paradigm (Tsuchiya & Koch, 2005), in which the target is projected to one eye and constantly flashing high-contrast masks are projected to the other eye. Interocular suppression by the masks causes participants to be unaware of the target for some time. Studies have adopted the CFS paradigm to examine whether people can process high-level information unconsciously. For instance, Yang and Yeh (2018b) showed that emotional faces under CFS facilitated the judgment of the following affective words (i.e., unconscious emotion priming). Jiang, Costello, Fang, Huang, and He (2006) found that nude photos captured people's attention under CFS, suggesting that the arousal information of pictures can be processed unconsciously. In Schmack, Burk, Haynes, and Sterzer (2016), participants' brain activity predicted how much faster for fearful stimuli to break through CFS compared to neutral stimuli by adopting a multivoxel pattern analysis (MVPA). Vetter, Badde, Phelps, and Carrasco (2019) also showed that subliminal emotional faces can guide eye movements; namely, participants' gaze directions moved toward the suppressed fearful faces but moved away from the suppressed angry faces even without awareness of the stimuli.

In line with previous studies investigating the priority for pictures and words to access awareness (e.g., for words: Hung & Hsieh, 2015; Prioli & Kahan, 2015; Yang & Yeh, 2011; for pictures: Hung, Nieh, & Hsieh, 2016; Shang et al., 2020), we examined this topic using the breaking CFS (b-CFS) paradigm by measuring the time for participants to perceive the masked target (Jiang, Costello, & He, 2007). Weng et al. (2019) showed that food pictures break through CFS faster than non-food pictures, providing the first evidence that food stimuli can access awareness faster than daily utensils (i.e., non-food stimuli). Here, we aimed to examine whether high-calorie foods and low-calorie foods access awareness with different priorities. Namely, we investigated the priority in accessing awareness for stimuli at the subordinate level (stimuli within the same category, e.g., cabbage and fried chicken both belong to the category "food", whereas fried chicken and clock belong to different categories). As food brings us energy and positive emotions, we hypothesized that food pictures triggering higher arousal would access awareness earlier compared to those triggering lower arousal. By contrast, given that words with emotional information enter awareness more slowly than those without, we hypothesized that food words triggering higher arousal would access awareness more slowly than those triggering lower arousal.

In four experiments, we reported results from stimuli of high versus low calories under CFS. We first used food pictures and words in Experiment 1 and verified the results of words from another set of food words in Experiment 2. Two control experiments followed, aiming to test whether low-level features of food pictures (Experiment 3) or response biases (Experiment 4) contribute to the results.

2. Experiment 1

In Experiment 1, we examined the b-CFS times to access awareness for food stimuli with high-calorie versus low-calorie information in the form of pictures and words. We hypothesized that high-calorie food pictures would access awareness faster than low-calorie food pictures, whereas low-calorie food words would access awareness faster than high-calorie food words.

2.1. Methods

2.1.1. Participants

We calculated our required sample size based on the effect size of Lin and Yeh (2016) which investigated the interocular grouping phenomenon using CFS (Experiment 1, Cohen's $d = 0.72$). Eighteen participants were required to reach 80% of power calculated by G*Power 3 (Faul, Erdfelder, Lang, & Buchner, 2007).

To this end, 20 participants were recruited in the current experiment. All participants (10 females, 19–22 years old, BMI: 17.54–27.73) were native Taiwanese with proficiency in reading and writing traditional Chinese. They had normal or corrected-to-normal vision and were not vegetarian and had no psychological or neurological disorders. They gave informed consent before the experiment and were rewarded with 150 NTD or course credits for their participation. This study was approved by the Research Ethics Committee at National Taiwan University and was implemented accordingly.

2.1.2. Stimuli and apparatus

A 27-inch LCD monitor was used to present visual stimuli (60 Hz refresh rate, spatial resolution: 1024 × 768 pixels). The display was manipulated using MATLAB (The MathWorks) Psychtoolbox. Ten colorful food pictures (extending 8.5° horizontally and 7° vertically) were used as target stimuli; half were high-calorie foods and half were low-calorie foods (see Appendix for the experimental stimuli and individual differences in b-CFS times). The Mondrian masks (extending 20° vertically and horizontally) were created as in Yang and Yeh (2014) that were filled with rectangular color patches of randomly selected sizes (from 0.02° to 1.07°) and randomly selected colors.

Another group of 20 participants was recruited to rate the calories of the food pictures and their arousal on a 7-point Likert scale. Calorie and arousal ratings were higher in high-calorie food pictures than low-calorie ones (Calorie: $t(19) = 24.45$, $p < .001$; Arousal: $t(19) = 3.58$, $p = .002$). There was a positive correlation between calorie and arousal ratings ($r = 0.78$, $p = .008$).

For the word stimuli, the 10 two-character traditional Chinese words (extending 3° horizontally and 2° vertically) corresponding to the food pictures were used as word stimuli. The number of strokes for the words of high-calorie foods (M = 25.4) and low-calorie foods (M = 21.4) were matched, $t(4) = -1.47$, $p = .215$.

In the b-CFS task, the Mondrian mask and the target image were projected to each participant's dominant eye and non-dominant eye, respectively. Two different pictures converged into one through a four-mirror stereoscope, consisting of two fixed mirrors angled 45° orthogonally and two adjustable mirrors centered nearby.

2.1.3. Design and procedure

Participants conducted two blocks of b-CFS tasks, with food pictures (the picture block) and Chinese words (the word block) as targets, respectively (Fig. 1A). The task order was counterbalanced across participants. Before the experiment, participants were asked to provide their height and weight, and current satiety state on an 8-point Likert scale. Then, participants were instructed to sit in a dark and sound-attenuated room with the head stabilized on a chin-rest, where their eyes were 57 cm from the monitor.

The b-CFS task contained one block with a total of 100 trials, in which 50 trials were high-calorie food targets and the other 50 trials were low-calorie food targets (Fig. 1A). Ten food pictures (words) were presented 10 times each during the task in random order. Participants were instructed to press the "z" button on the keyboard to initiate a trial and the "x" button as soon as they perceived anything other than the flashing mosaic (i.e., the Mondrian). Then, participants conducted the location judgment task by choosing the location of the target with the up and down arrow buttons using their right hand. They were told to press the key immediately after detecting the target but conduct the location judgment task at their own pace and as accurately as possible. If

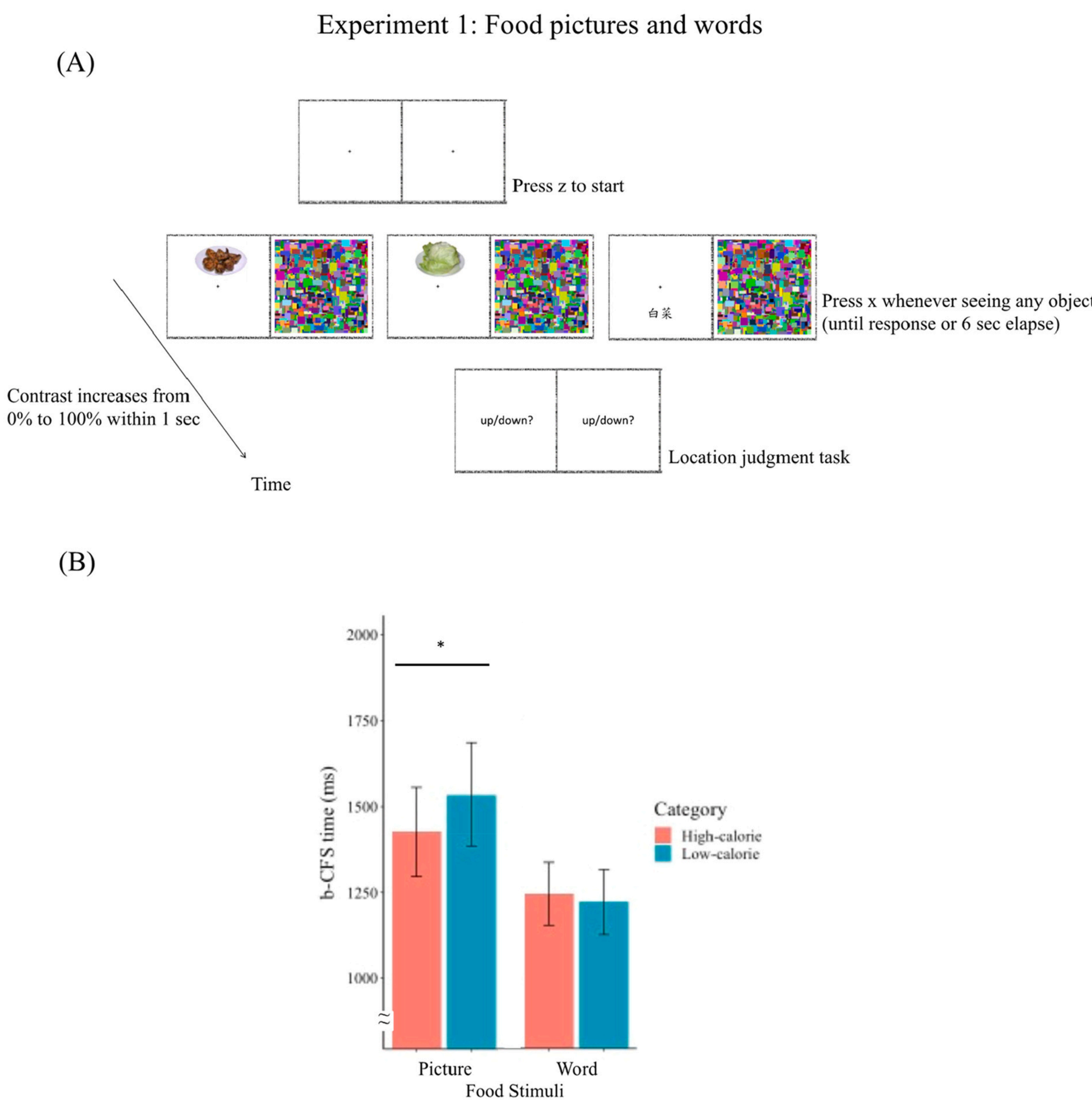

Fig. 1. Procedures and results in Experiment 1. (A) The procedure of an example of a high-calorie food picture (left; "roast chicken"), low-calorie food picture (middle; "cabbage"), and low-calorie food word (right; "cabbage") (B) Mean b-CFS time for pictures and words in Experiment 1. *: $p < .05$.

participants did not press the button within six seconds, they were still asked to guess the location of the stimuli even though these trials would not be included in data analysis.

After confirming that the binocular vision fused well with the four-mirror stereoscope, participants were told to conduct the task at their own pace. During a trial, a black fixation sign (a plus sign, extending 0.5° vertically and horizontally) on a white background remained at the center of the screen for both eyes, and the target ramped up from 0% to 100% contrast within 1 s. Half of the targets appeared in the upper visual field and the other half in the lower visual field (5° from the center of the picture to the center of the screen). The Mondrian mask flashed at 10 Hz (varied every 100 ms) with a contrast of 100%. The Mondrian mask and the target disappeared at the same time when participants pressed the "x" button or lapsed after 6 s.

After the b-CFS task, participants were instructed to rate the calorie, valence, arousal of the stimuli, and the frequency of seeing the words on a 7-point Likert scale to assure that the food pictures and Chinese words we chose were different in calories and arousal.

2.2. Results

2.2.1. Manipulation check after the CFS experiment

To ensure that the two categories of stimuli we chose were different in calorie and arousal, we compared the rating data obtained from the participants after the CFS experiment. Higher ratings for calorie (pictures: $t(19) = 23.64$, $p < .001$; words: $t(19) = 25.12$, $p < .001$) and arousal (pictures: $t(19) = 4.64$, $p < .001$; words: $t(19) = 3.54$, $p = .002$) were observed for both pictures and words. Positive correlations between calorie and arousal ratings were found in both picture stimuli ($r = 0.85$, $p = .002$) and word stimuli ($r = 0.77$, $p = .015$). These indicate that manipulation of food pictures and words with the difference in calories used in this experiment was successful. There were no differences in frequency of seeing these stimuli between high-calorie and low-calorie foods (pictures: $t(19) = 0.18$, $p = .856$; words: $t(19) = 1.24$, $p = .23$). For valence ratings, we found no difference for high-calorie versus low-calorie food words ($t(19) = 1.89$, $p = .074$) but a higher valence for high-calorie pictures than low-calorie pictures ($t(19) = 2.55$, $p = .019$).

2.2.2. b-CFS time

Fig. 1B shows the results of Experiment 1. In all the experiments reported in this study, b-CFS time was analyzed after removing trials with no response in the b-CFS task and incorrect responses in the location judgment task. The no-response rate was 1.4% in the picture block and 1% in the word block. The accuracy in the location judgment task was 99.15% for the picture block and 98.3% for the word block.

As subjective sensitivity might contribute to individual differences in b-CFS time (Sklar et al., 2021), we performed the linear-mixed effect (LME) model analysis to control the random intercepts of Subject and Stimulus while examining the fixed effect of Calorie and Form on the b-CFS time using the lme4 (Bates, 2010) and lmerTest (Kuznetsova, Brockhoff, & Christensen, 2017) packages in R. The full model had the structure: b-CFS time ~ Calorie + Form + Calorie*Form + (1|Subject) + (1|Stimulus). The likelihood-ratio chi-square test was used to compare the performance of the full and reduced models. Here, a significant interaction between Calorie and Form was observed by comparing the full model with the model without the interaction term ($\chi^2(1) = 8.9$, $p = .003$). A main effect of Form was observed ($\chi^2(1) = 133.78$, $p < .001$), suggesting a faster b-CFS time for word stimuli than picture stimuli. No main effect of Calorie was observed ($\chi^2(1) = 2.05$, $p = .153$).

To reveal the cause of the interaction, the simple main effect of the interaction was evaluated using the lsmeans package in R (Lenth, 2016). Faster b-CFS times were observed in high-calorie pictures (M = 1435.95 ms) versus low-calorie pictures (M = 1535.94 ms), $p = .002$. On the other hand, no difference in b-CFS times were observed in high-calorie words (M = 1243.79 ms) versus low-calorie words (M = 1220.55 ms), $p = .465$.

We also calculated the normalized latency (median b-CFS time differences across the conditions of interest divided by overall median b-CFS time; Gayet & Stein, 2017) to verify our results. The normalized latency uses the median b-CFS time(s) to account for the potential skewnewss of the distribution in the raw b-CFS time(s). By dividing the overall median b-CFS time, it can remove the uninteresting between-subject variability that might dilute the effect of interest. Here, the normalized latency also provided supporting evidence for the faster b-CFS times in high-calorie than low-calorie food pictures, $\Delta RT_{normalized} = 5.69$, $t(19) = 2.82$, $p = .006$ (one-tailed). There was no difference of b-CFS times across calories for word stimuli, $\Delta RT_{normalized} = 1.29$, $t(19) = 0.91$, $p = .812$ (one-tailed). No significant correlations were found between b-CFS time difference and BMI (pictures: $r = -0.2$, $p = .395$, words: $r = -0.21$, $p = .369$) and satiety state (pictures: $r = -0.31$, $p = .191$, words: $r = -0.16$, $p = .495$) in both forms of presentation.

In the current analysis, we did not find a difference in the b-CFS time of Chinese words between high-calorie and low-calorie foods. However, the character "雞" (chicken) was repeated in two of the word stimuli in the high-calorie food category. We thus conducted Experiment 2 to rule out the possible confound here.

3. Experiment 2

In Experiment 1, we have shown that food pictures with higher calories have a higher priority in accessing visual awareness than those with lower calories. Here, we tested the word stimuli again by avoiding the potential confound of repetition in the stimulus set in Experiment 1. We expected to see words with lower arousal (low-calorie food words) enter awareness faster than words with higher arousal (high-calorie food words), showing that the emotional information embedded in words interfere with the ongoing lexical access at the pre-conscious level (Larsen et al., 2008).

3.1. Methods

3.1.1. Participants

Twenty-one new participants were recruited. Two participants were excluded from the data analysis due to low accuracy in the location judgment task and high no-response rates in the b-CFS task (less than 70% of valid trials; one participant had a 51% no-response rate and the other had a 27% no-response rate and 6% error rate in the location judgment task). Therefore, 19 participants (11 females, 18–26 years old, BMI: 18.36–27.74) were included in the following analysis. Other criteria were the same as in Experiment 1.

3.1.2. Stimuli and apparatus

The same words in Experiment 1 were used as target stimuli (with the same stimulus size), but one food word was changed from "烤雞" (roast chicken) to "烤鴨" (roast duck) to avoid repetition of the Chinese character "雞" (another word was "炸雞", fried chicken). Other settings were the same as Experiment 1. Number of strokes in the high-calorie foods (M = 25) and low-calorie foods (M = 21.4) were matched, $t(4) = 1.45$, $p = .22$.

3.1.3. Design and procedure

The design and procedure were the same as the word block of Experiment 1 (Fig. 2A), except for one food word. Participants were instructed to rate the calorie, valence, arousal of the stimuli, and the frequency of seeing the words on a 7-point Likert scale after the CFS experiment, to assure that the Chinese words we chose were different in calories and arousal but equivalent in other domains.

3.2. Results

3.2.1. Manipulation check after the CFS experiment

Calorie and arousal ratings were higher for high-calorie food words

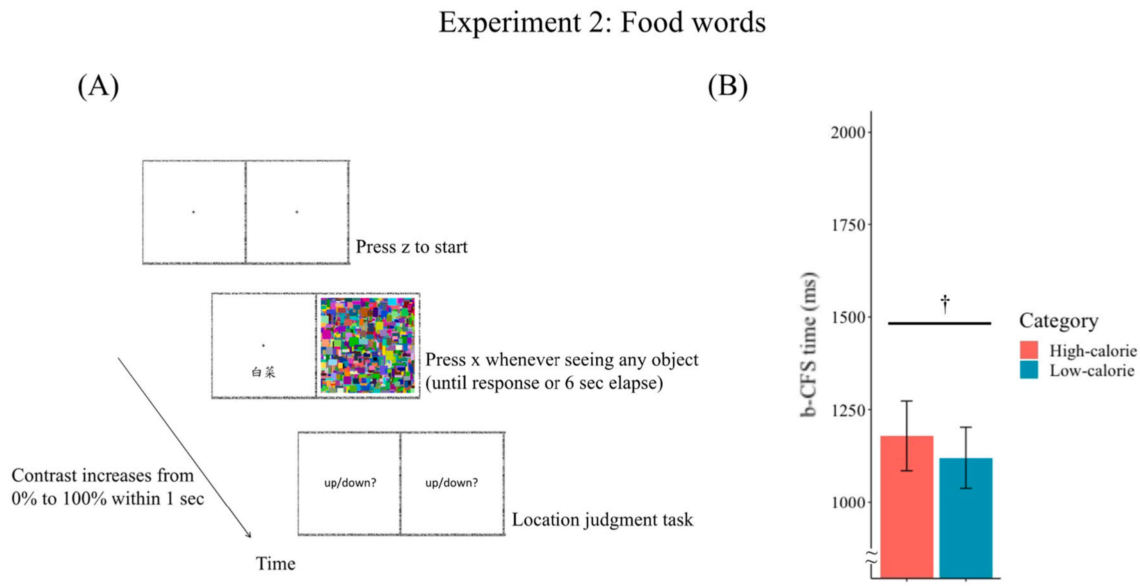

Fig. 2. Procedures and results in Experiment 2. (A) The procedure of an example of a low-calorie food word ("cabbage") (B) Mean b-CFS time in Experiment 2. †: $p < .1$.

than low-calorie food words (calorie: $t(18) = 15.91$, $p < .001$; arousal: $t(18) = 2.45$, $p = .023$), and a positive correlation between calorie and arousal ratings was found ($r = 0.72$, $p = .018$). There were no differences in frequency of seeing these words ($t(18) = -2.06$, $p = .054$) and valence ($t(18) = 0.9$, $p = .382$) between ratings of high-calorie and low-calorie food words. The rating data here suggested that the high-calorie and low-calorie words we chose were only different in calorie and arousal but not in other domains.

3.2.2. b-CFS time

The no-response rate was 0.7%, and the accuracy of the location judgment task was 97.37%. The LME analysis was performed by treating Calorie as a fixed-effect factor while Subject and Stimulus as random intercepts, where the model had the structure: b-CFS time ~ Calorie + (1|Subject) + (1|Stimulus). A marginal main effect of Calorie was observed, $\chi^2(1) = 2.92$, $p = .087$, suggesting faster b-CFS times in low-calorie words (M = 1119.92 ms) than high-calorie words (M = 1179.09 ms). The normalized latency also provided supporting evidence showing that low-calorie words indeed access awareness faster than high-calorie words, $\Delta RT_{normalized} = 3.06$, $t(18) = 1.76$, $p = .048$ (one-tailed). No correlations were found between b-CFS time difference in high-calorie versus low-calorie food words and BMI ($r = -0.29$, $p = .225$) as well as between b-CFS time difference and satiety state ($r = -0.02$, $p = .924$).

4. Experiment 3

Previous studies (e.g., Moors, Hesselmann, Wagemans, & van Ee, 2017) have shown that b-CFS tasks often suffer from low-level interference; the difference in b-CFS times across conditions might not be the direct result of differences in the time for the target stimuli to access awareness, but rather, effects from low-level features of the pictures. Experiment 3 was designed to test this possibility.

In Experiment 3, we adopted diffeomorphic transformations (Stojanoski & Cusack, 2014), also adopted by other studies investigating unconscious processing with b-CFS (Salomon et al., 2016), to scramble the pictures used in Experiment 1. A diffeomorphic transformation is an approach to eliminating high-level information of pictures (such as the identity) while preserving all low-level features (e.g., size, luminance, spatial power) by adding random noise of cosine waves into the spatial power spectrum of the picture. If low-level features contributed to the difference in b-CFS times, we should observe a difference in b-CFS times between high-calorie and low-calorie foods with the diffeomorphic pictures as stimuli. Conversely, if the meanings of the pictures contributed to the difference in b-CFS times, no difference in b-CFS times should be observed when using diffeomorphic pictures as stimuli.

4.1. Methods

4.1.1. Participants

Twenty new participants were recruited. One participant was excluded from the data analysis due to low accuracy in the location judgment task and high no-response rates in the b-CFS task (less than 70% valid trials; 49% of no-response rate). Therefore, 19 participants (9 females, 18–26 years old, BMI: 17.71–27.08) were included in the following analysis. Other criteria were the same as in Experiments 1 and 2.

4.1.2. Stimuli and apparatus

Ten food pictures in Experiment 1 were diffeomorphically transformed and used as the stimuli here. To avoid unnecessary top-down factors that might influence b-CFS times, 18 participants (who did not participate in any of the experiments in this study) were recruited to rate stimuli for recognizability, valence, and arousal. Recognizability was rated as in Stojanoski and Cusack (2014) with a 4-point Likert scale: 1 (no, not at all), 2 (I'm not sure, but I can take a guess), 3 (I can see it fairly well), and 4 (I know exactly what it is). The valence and arousal of the pictures were rated on a 7-point Likert scale. There was also an optional question where participants could guess what the stimulus was at the end of each picture's rating if they thought they knew what the stimulus was. None of the pictures were rated higher than 2 in the rating of recognizability based on the one-sample t-test (Picture 1: $t(17) = -2.72$, $p = .993$; Picture 2: $t(17) = -1.84$, $p = .959$; Picture 3: $t(17) = -2.38$, $p = .985$; Picture 4: $t(17) = -4.58$, $p = 1.00$; Picture 5: $t(17) = 0$, $p = .5$; Picture 6: $t(17) = -2.71$, $p = .993$; Picture 7: $t(17) = -2.06$, $p = .973$; Picture 8: $t(17) = -0.7$, $p = .752$; Picture 9: $t(17) = -4.27$, $p = 1.00$; Picture 10: $t(17) = -2.12$, $p = .976$). Moreover, no participants gave a correct guess to any of the diffeomorphic pictures. For the valence rating, pictures did not bring either positive or negative feelings toward participants ($t(17) = -0.99$, $p = .338$, compared to 4, neutral). We also compared recognizability, valence, and arousal ratings between two categories (high and low calories) of diffeomorphic pictures. No differences were found in recognizability ($t(17) = -0.67$, $p = .508$) and valence ($t(17) = 0.76$, $p = .456$), but a higher arousal rating was found for low-calorie than high-calorie diffeomorphic pictures ($t(17) = 3.45$, $p = .003$).

Before this experiment, we conducted a pilot study using diffeomorphic food stimuli. We collected data from 25 participants to experiment with a procedure similar to Experiment 1 except for the food picture stimuli (i.e., they were diffeomorphically transformed). Ten participants could not easily break the CFS during the task, given that they had less than 70% valid trials (33.5% no-response rate). Even though there was no significant difference in b-CFS times across the low-calorie and high-calorie diffeomorphic pictures ($\chi^2(1) = 1.35$, $p = .245$), the result might suffer from insufficient power. Ten out of 25 participants could not break CFS within six seconds due to the high target-mask similarity, which increased the required time for stimuli to access awareness (Pournaghdali & Schwartz, 2020). Therefore, in Experiment 3, to reduce the similarity between the target and the mask (which thus avoided the high exclusion rate), the Mondrian masks were created using the same approach as in Experiment 1 with two differences: changing the shapes of the mask elements into ovals and their colors into grayscale.

4.1.3. Design and procedure

The design and procedure were the same as in Experiment 1 except for the mask, experimental stimuli, and ratings (Fig. 3A). Participants were instructed to rate the recognizability, valence, and arousal of the 10 diffeomorphic pictures to ensure that these pictures were not recognizable. These ratings were done after the CFS experiment as in Experiments 1 and 2.

4.2. Results

4.2.1. Manipulation check after the CFS experiment

The recognizability of all stimuli was not greater than 2 on a 4-point Likert scale rating based on the one-sample *t*-test (Fig. D in Appendix, from left to right: Picture 1: $t(18) = -4.98$, $p = 1.00$; Picture 2: $t(18) = -2.67$, $p = .992$; Picture 3: $t(18) = -3.29$, $p = .998$; Picture 4: $t(18) = -6.43$, $p = 1.00$; Picture 5: $t(18) = -8.22$, $p = 1.00$; Picture 6: $t(18) = -4.61$, $p = .999$; Picture 7: $t(18) = -2.96$, $p = .996$; Picture 8: $t(18) = -1.56$, $p = .931$; Picture 9: $t(18) = -3.29$, $p = .998$; Picture 10: $t(18) = -3.02$, $p = .996$), suggesting that the stimuli could not be recognized by the participants. Low-calorie diffeomorphic pictures brought participants a more positive emotion than high-calorie diffeomorphic pictures ($t(18) = -2.4$, $p = .027$) and no difference in arousal was observed ($t(18) = -1.01$, $p = .327$).

4.2.2. b-CFS time

The no-response rate was 2%, and the accuracy of the location judgment task was 99.21%. An LME analysis was performed by treating Calorie as a fixed-effect factor while Subject and Stimulus as random intercepts. The model had the same structure as the one in Experiment 2. There was no difference in the b-CFS times in high-calorie (M = 1542.34 ms) versus low-calorie (M = 1587.6 ms) diffeomorphic pictures, $\chi^2(1) = 0.22$, $p = .639$ (Fig. 3B). No correlations were found between b-CFS time difference in high-calorie versus low-calorie pictures and BMI ($r = 0.19$, $p = .444$) and satiety state ($r = -0.28$, $p = .254$).

Note that another group of participants rated low-calorie diffeomorphic pictures as higher in arousal in the pilot rating, while the participants in this experiment rated low-calorie diffeomorphic pictures to be more positive. Had these differences influenced the results, we should have observed faster b-CFS times in low-calorie diffeomorphic pictures. However, no b-CFS time difference was observed between high-calorie and low-calorie diffeomorphic pictures.

4.2.3. Comparison of Experiments 1 and 3

To examine whether low-level features of picture stimuli play any role in determining the b-CFS times, we compared the b-CFS times of food pictures in Experiment 1 and those of the diffeomorphic pictures in Experiment 3 using the LME analysis. Calorie (high, low) and Experiment (Experiment 1, Experiment 3) were treated as fixed-effect factors while Subject and Stimulus were treated as random intercepts to perform an LME analysis. The full model had the structure: b-CFS time ~ Calorie + Experiment + Calorie * Experiment + (1|Subject) + (1|Stimulus). If the low-level features did not contribute to the b-CFS times at all, we should observe an interaction between Calorie and Experiment, where the different b-CFS times in high-calorie and low-calorie food pictures were only observed in Experiment 1 but not Experiment

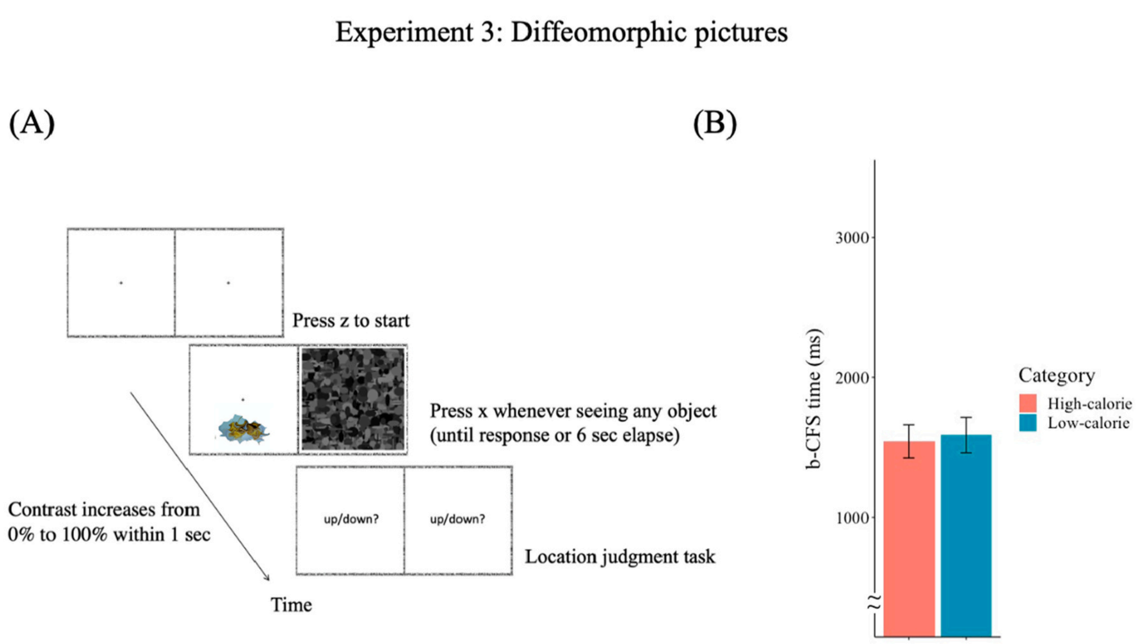

Fig. 3. Procedures and results in Experiment 3. (A) The procedure of an example of a diffeomorphic picture with grayscale oval-shaped masks. (B) Mean b-CFS time in Experiment 3.

3. However, the interaction ($\chi^2(1) = 2.3$, $p = .13$) was not significant[1], nor the main effects of Calorie ($\chi^2(1) = 2.14$, $p = .144$) and Experiment ($\chi^2(1) = 0.22$, $p = .637$). Despite the different b-CFS times across calories were found in Experiment 1, the absence of interaction here suggested that low-level features of the pictures still played certain roles in determining the b-CFS times (Stein, Awad, Gayet, & Peelen, 2018).

5. Experiment 4

One may also doubt that our results in Experiments 1 and 2 were due to post-perceptual response bias rather than the genuine time difference for different calories of food and form (i.e., pictures and words) to access awareness. Therefore, Experiment 4 aimed to solve this issue by presenting the stimuli with binocular but not dichoptic viewing (Jiang et al., 2007; Tan & Yeh, 2015; Yang & Yeh, 2011), using both picture and word stimuli. If the faster breaking times of high-calorie pictures and low-calorie words were due to response bias, then we should observe the same result pattern as in Experiments 1 and 2, respectively (i.e., faster detection time for high-calorie pictures and low-calorie words). Otherwise, no difference in detection times between high-calorie and low-calorie stimuli should be found in both pictures and words while viewing them binocularly.

5.1. Methods

5.1.1. Participants

Twenty new participants were recruited (10 females, 18–29 years old, BMI: 17.53–29.68). Other criteria were the same as Experiments 1, 2, and 3.

5.1.2. Stimuli and apparatus

The stimuli and apparatus were the same as in Experiments 1 and 2, except that the target and the Mondrian mask were superimposed and presented in both eyes (Fig. 4A).

5.1.3. Design and procedure

The design and procedure were the same as in Experiment 1 except that now the participants were instructed to conduct two blocks of visual detection tasks: one block with picture stimuli and one block with word stimuli, with the order counterbalanced across participants.

5.2. Results

5.2.1. Manipulation check after the CFS experiment

Higher rating scores of calorie and arousal were found for high-calorie foods than low-calorie foods in both pictures (calorie: $t(19) = 46.47$, $p < .001$; arousal: $t(19) = 5.94$, $p < .001$) and words (calorie: $t(19) = 29.14$, $p < .001$; arousal: $t(19) = 3.96$, $p < .001$). Positive correlations between calorie and arousal were found in picture stimuli ($r = 0.88$, $p < .001$) and word stimuli ($r = 0.73$, $p = .016$). No other differences between ratings of high-calorie foods and low-calorie foods were found (Picture stimuli, frequency of seeing: $t(19) = -1.4$, $p = .178$; valence: $t(19) = 1.45$, $p = .163$; Word stimuli, frequency of seeing: $t(19) = 0.61$ $p = .551$; valence: $t(19) = 1.25$, $p = .225$).

5.2.2. Detection time

Fig. 4B shows the results of Experiment 4. The no-response rates were 0% in both picture and word blocks and the accuracy in the location judgment task was 99.1% for the picture block and 99.3% for the word block. An LME analysis was performed by treating Calorie and Form (i.e., picture, word) as fixed-effect factors while Subject and Stimulus as random intercepts. The model had the same structure as the one in Experiment 1. A main effect of Form was observed ($\chi^2(1) = 43.7$, $p < .001$), where the detection time for words (M = 720.31 ms) were faster than that for pictures (M = 765.69 ms). Neither the main effect of Calorie ($\chi^2(1) = 2.63$, $p = .105$) nor the interaction between Calorie and Form ($\chi^2(1) = 0.2$, $p = 653$) was observed.

5.2.3. Comparison of Experiments 1, 2, and 4

To further examine if the results were free from response bias, we compared the b-CFS times (detection times) of Experiments 1, 2, and 4. Two LME analyses were administered to the food pictures and food words separately by treating the Calorie and Viewing condition (i.e., interocular vs. binocular viewing) as fixed-effect factors and Subject and Stimulus as random intercepts. The full model had the structure: b-CFS time ~ Calorie + Viewing-condition + Calorie * Viewing-condition + (1|Subject) + (1|Stimulus). For picture stimuli, a main effect of Viewing condition ($\chi^2(1) = 19.98$, $p < .001$) and a marginal main effect of Calorie ($\chi^2(1) = 3.41$, $p = .065$) were found. Most importantly, a significant interaction between Calorie and Viewing condition was observed ($\chi^2(1) = 12.89$, $p < .001$). The simple main effect of the interaction was evaluated using the lsmeans package in R (Lenth, 2016). A significant difference in b-CFS times were observed in the interocular-viewing condition ($p < .001$) but not the binocular-viewing condition ($p = .784$). For word stimuli, main effects of Viewing condition ($\chi^2(1) = 16.47$, $p < .001$) and Calorie ($\chi^2(1) = 4.71$, $p = .03$) were observed. A marginal interaction between Calorie and Viewing condition ($\chi^2(1) = 3.33$, $p = .068$) was observed. The simple main effect analysis revealed a significant difference in b-CFS times in the interocular-viewing condition ($p = .002$) but not in the binocular-viewing condition ($p = .438$). The analyses here suggest that the difference in b-CFS (detection) times was more pronounced in the interocular-viewing condition than the binocular-viewing condition.

The results here indicate that the b-CFS time differences of high-calorie and low-calorie food did not vary in pictures or words at the conscious level. Most importantly, the results suggest that the differences of b-CFS times found in Experiments 1 and 2 did not result from response biases.

6. General discussion

We provided the first evidence that the mechanisms of unconscious processing are distinct for pictures and words under CFS with the same experimental framework. Results in Experiments 1 and 2, taken together, showed that high-arousal pictures and words had reverse patterns in accessing awareness: the b-CFS time was faster for high-calorie foods than low-calorie foods in pictures (Experiment 1), but was slower for high-calorie foods than low-calorie foods in words (Experiment 2). A similar pattern of results was found in Yang et al. (2007) and Yang and Yeh (2011). Yang et al. (2007) found a faster b-CFS time for negative facial expressions than neutral faces, whereas Yang and Yeh (2011) found a slower b-CFS time for negative words than neutral words. Unlike these two studies that used different sets of face and word stimuli, here we demonstrated opposite latency patterns of pictures and words in accessing awareness within the same set of experimental frameworks and stimuli. Furthermore, in Experiment 3, we verified that our results of picture stimuli did not exclusively result from the interference of low-level features: b-CFS times were equivalent for diffeomorphic pictures of high-calorie and low-calorie foods. Additionally, in Experiment 4, we showed that the b-CFS time differences did not result from post-perceptual response bias: the detection times were equivalent across stimuli with high versus low calories when the target and mask were superimposed and viewed binocularly.

Given that we did not find correlations between b-CFS times and satiety state, as well as BMI, we believe that homeostasis and body

[1] Despite no interaction between Calorie and Experiment, we performed the planned simple effect analysis using the lsmeans package in R (Lenth, 2016). Faster b-CFS times in high-calorie versus low-calorie foods were only observed in comparing food pictures used in Experiment 1 ($p = .043$) but not in comparing diffeomorphic pictures used in Experiment 3 ($p = .445$).

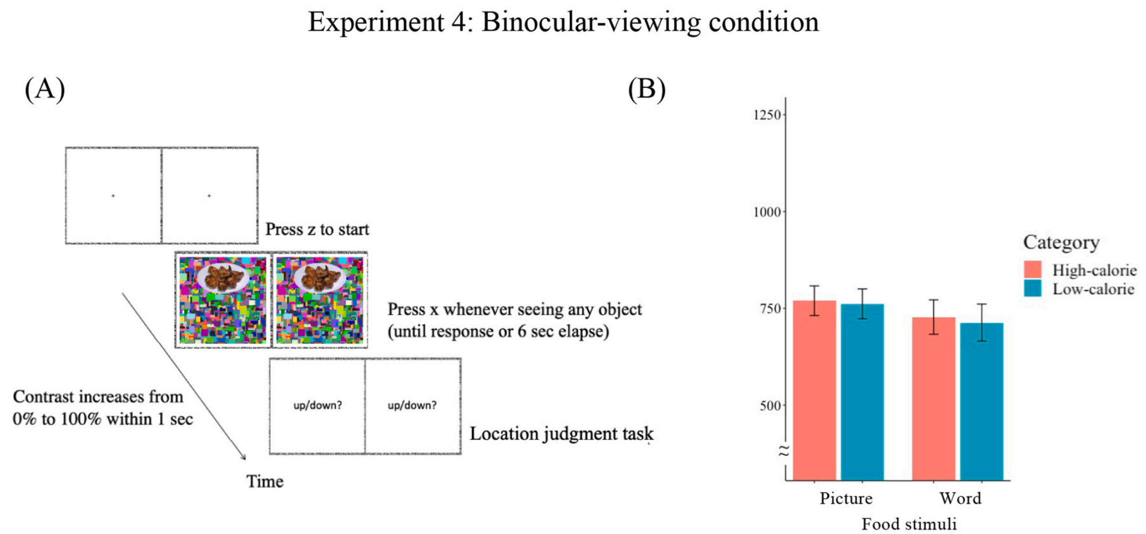

Fig. 4. Procedures and results in Experiment 4. (A) The procedure of an example of a binocular-viewing condition using pictures as stimuli. (B) Mean detection time for pictures and words in Experiment 4.

composition were not the primary causes of the differences we found in the b-CFS times here. The reason why our results showed that participants' satiety state did not influence the b-CFS times may lie in the perceptual task we used here. Previous studies have shown that participants' homeostatic state affects subliminal priming. For example, Karremans, Stroebe, and Claus (2006) showed that only thirsty participants were influenced by subliminal primes in their choice to drink a specific brand of soft drink (see also Bermeitinger et al., 2009). Similar results were found in Sato, Sawada, Kubota, Toichi, and Fushiki (2017) that only hungry participants showed the subliminal priming effect of food pictures. These studies establishing the relationship between priming and homeostasis used behavioral changes as the index of subliminal priming and adopted a choice- or decision-making task. In contrast, we used a perceptual detection task for the b-CFS experiments, and thus it is likely to be cognitively impenetrable (Firestone & Scholl, 2014, 2016).

Participants' BMIs did not affect the b-CFS times for the following two reasons. First, we did not collect participants' fat levels during recruitment, and some of them likely had a high BMI but low-fat levels, as commonly found in athletes. Therefore, the BMI which measures total weight including the weights of muscles and organs might not be the best index for people's craving for food, if any. Second, Werthmann et al. (2011) have shown that overweight people showed an avoidance pattern to food with high fat: They gave their first gaze to the food pictures yet subsequently moved their gaze away. Thus, overweight individuals' cognitive processes regarding food are more complicated than what we can capture here. People with higher BMI may allocate their attention to the food pictures first but disengage from the target right away, which cancels out the benefit or cost of high-calorie foods in accessing awareness.

What was the reason for a faster b-CFS time in high-calorie pictures and low-calorie words than their counterparts? In addition to the emotional information in words that might interfere with the lexical process (Larsen et al., 2008), attentional capture may play a major role here. Our rating results showed that low-calorie foods were lower in arousal and closer to neutral regardless of the form (pictures or words). Hinojosa et al. (2009) showed that high-arousal pictures and neutral words, compared to their counterparts, elicit a more prominent late positive component (LPC) of event-related potentials (ERPs), the electrophysiological index of attentional resource mobilization and emotional engagement (Bradley & Lang, 2007; Schupp et al., 2007). Furthermore, the time window of the LPC in words (350–425 ms) was also earlier than that in pictures (450–550 ms). These results suggest that when stimuli must be processed quickly without paying much attention to their emotional content (i.e., not required to do semantic judgment or categorization), high-arousal pictures and neutral words tend to capture more attentional engagement than low-arousal pictures and emotional words, respectively. Similar results were obtained by Citron, Weekes, and Ferstl (2013), in which they found a more prominent LPC component for neutral words than affective words. In addition, Robinson et al. (2004) found that high-arousal pictures were identified more quickly, whereas high-arousal words were identified more slowly, than low-arousal pictures and words, respectively. In summary, high-calorie food pictures and low-calorie food words capture participants' attention and gain access to awareness faster than their counterparts, an explanation supported by electrophysiological results (Chen, Lin, Chen, Lu, & Guo, 2015; Citron et al., 2013; Hinojosa et al., 2009; Naccache et al., 2005).

Our study went a step further by comparing the b-CFS times of items in the same category (i.e., high-calorie vs. low-calorie foods) instead of foods versus non-foods. Weng et al. (2019) found that food pictures break through suppression faster than non-food objects. Sato, Sawada, Kubota, Toichi, and Fushiki (2016) used an affective priming task with backward masking to show that food can unconsciously bring us positive emotions. The present study, however, showed that information from the subordinate level (stimuli within the same category) can have different priorities to access visual awareness, as shown here that different calories of foods yielded different b-CFS times.

High-level information, such as semantics, can be processed unconsciously (Hung, Wu, & Shimojo, 2020; Yang & Yeh, 2011; Yeh, He, & Cavanagh, 2012). Even though it is still debated whether b-CFS time results can be interpreted as unconscious processing (Stein, Hebart, & Sterzer, 2011), we believe that our study has provided another piece of evidence that high-level information survives CFS, which is also in line with our previous findings. For example, Yang and Yeh (2011) have shown that neutral Chinese words break through suppression faster than negative Chinese words. By adopting ERPs, Yang et al. (2017) also showed that the N400 component was sensitive to the lexical congruency and semantic relatedness, even when the stimuli were rendered invisible by CFS. Another paradigm of visual suppression, visual crowding, also revealed participants' ability to access semantics even when words were not consciously recognized (Yeh et al., 2012). Studies from research groups with other language systems also showed that high-level information survives CFS, such as semantics (Eo, Cha, Chong, & Kang, 2016; Hung et al., 2020; Prioli & Kahan, 2015), syntactic (Hung & Hsieh, 2015, 2021), attractiveness (Hung et al., 2016; Shang et al., 2020), and arithmetic (Karpinski, Briggs, & Yale, 2019; Sklar et al., 2012; but see Rabagliati et al., 2018; Shanks, 2017). Indeed, by adopting MVPA, Sheikh et al. (2019) showed that people can process semantic information unconsciously, and different languages rely on different brain mechanisms to do so.

Limitations regarding the between-subject design and the statistics should be addressed. First, we recruited different groups of participants to verify the effect(s) of food pictures (Experiment 1), food words (Experiment 2), diffeomorphic pictures (Experiment 3), and binocular-viewing conditions (Experiment 4). An advantage of recruiting different participants across experiments is to decrease the practice effect of Mondrian masks, where the target detection threshold will decrease after hundreds of trials of training (Ludwig, Sterzer, Kathmann, Franz, & Hesselmann, 2013). A within-subject design might be able to decrease the group variance. However, before conducting the experiment using diffeomorphic pictures, counterbalancing the order of the task might expose participants to the intact food pictures, and the carryover effect may thus contaminate the b-CFS times for the diffeomorphic pictures. Future studies can use a within-subject design to reduce the between-subject variance when running cross-experiment comparisons and try to avoid the carry-over effect. Second, the b-CFS time difference found in food words was not as pronounced as that with food pictures. It should be noted that high-level information in words has a relatively weak signal-to-noise ratio when rendered subliminal (Hung et al., 2020; Hung & Hsieh, 2021; Naccache et al., 2005), and a lengthened exposure time is needed to extract the high-level information unconsciously. For b-CFS studies, another method to examine the priority for different categories of stimuli to access awareness would be measuring the needed contrast and time for them to be detected psychophysically (Stein, 2019). Third, we did not observe an interaction between calories and picture forms when comparing the results from food pictures (Experiment 1) and diffeomorphic pictures (Experiment 3). This suggested that low-level features of the picture stimuli still contribute to the b-CFS time difference between high-calorie and low-calorie pictures to a certain degree. Given that most food stimuli are still recognizable when rendered inverted, we could not use the inverted pictures as control stimuli as most CFS studies did (e.g., Yang et al., 2007; Yang & Yeh, 2018a). Instead, we tried to preserve all the low-level features but remove the meaning of the food pictures via diffeomorphic transformation. To our knowledge, this was the best way to control the low-level features despite that diffeomorphic transformation might add extra edges to the pictures. All in all, future studies can address these concerns by using different approaches to measure the priority for stimuli to access awareness and to control low-level features.

In conclusion, we have shown that priorities for arousing stimuli to access awareness depend on the form (i.e., picture or word) in four experiments. This study revealed the dissociation of pictures and words in unconscious processing, and they access our visual awareness with different priorities. High-arousing stimuli do not always enter visual awareness earlier; instead, the form of the stimuli (i.e., picture or word) also plays a determining role in what we see first.

Open practices statement

The data and the experimental stimuli in this study are available from the link: https://osf.io/u9k8p/?view_only=7c04181355cc4d68b8f9e7c81ac7adb4. None of the experiments were preregistered.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.cognition.2022.105144.

References

Adams, W. J., Gray, K. L., Garner, M., & Graf, E. W. (2010). High-level face adaptation without awareness. *Psychological Science, 21*(2), 205–210.

Bates, D. M. (2010). *lme4: Mixed-effects modeling with R*. New York: Springer. Prepublication version at: http://lme4.r-forge.r-project.org/book/.

Bermeitinger, C., Goelz, R., Johr, N., Neumann, M., Ecker, U. K., & Doerr, R. (2009). The hidden persuaders break into the tired brain. *Journal of Experimental Social Psychology, 45*(2), 320–326.

Blechert, J., Meule, A., Busch, N. A., & Ohla, K. (2014). Food-pics: An image database for experimental research on eating and appetite. *Frontiers in Psychology, 5*, 617.

Bradley, M. M., & Lang, P. J. (2007). Emotion and motivation. In J. T. Cacioppo, L. G. Tassinary, & G. G. Berntson (Eds.), *Handbook of psychophysiology* (pp. 581–607). Cambridge University Press.

Cauchoix, M., & Crouzet, S. M. (2013). How plausible is a subcortical account of rapid visual recognition? *Frontiers in Human Neuroscience, 7*, 39.

Chen, P., Lin, J., Chen, B., Lu, C., & Guo, T. (2015). Processing emotional words in two languages with one brain: ERP and fMRI evidence from Chinese–English bilinguals. *Cortex, 71*, 34–48.

Cheng, K., Ding, A., Jiang, L., Tian, H., & Yan, H. (2019). Emotion in Chinese words could not be extracted in continuous flash suppression. *Frontiers in Human Neuroscience, 309*.

Citron, F. M., Weekes, B. S., & Ferstl, E. C. (2013). Effects of valence and arousal on written word recognition: Time course and ERP correlates. *Neuroscience Letters, 533*, 90–95.

Cohen, L., Dehaene, S., Naccache, L., Lehéricy, S., Dehaene-Lambertz, G., Hénaff, M. A., & Michel, F. (2000). The visual word form area: Spatial and temporal characterization of an initial stage of reading in normal subjects and posterior split-brain patients. *Brain, 123*(2), 291–307.

Eo, K., Cha, O., Chong, S. C., & Kang, M.-S. (2016). Less is more: Semantic information survives interocular suppression when attention is diverted. *Journal of Neuroscience, 36*(20), 5489–5497.

Faul, F., Erdfelder, E., Lang, A.-G., & Buchner, A. (2007). G* power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods, 39*(2), 175–191.

Firestone, C., & Scholl, B. J. (2014). "Top-down" effects where none should be found: The El Greco fallacy in perception research. *Psychological Science, 25*(1), 38–46.

Firestone, C., & Scholl, B. J. (2016). Cognition does not affect perception: Evaluating the evidence for "top-down" effects. *Behavioral and Brain Sciences, 39*, E229.

Garolera, M., Coppola, R., Muñoz, K. E., Elvevåg, B., Carver, F. W., Weinberger, D. R., & Goldberg, T. E. (2007). Amygdala activation in affective priming: A magnetoencephalogram study. *Neuroreport, 18*(14), 1449–1453.

Gayet, S., & Stein, T. (2017). Between-subject variability in the breaking continuous flash suppression paradigm: Potential causes, consequences, and solutions. *Frontiers in Psychology, 8*, 437.

Hinojosa, J. A., Carretié, L., Valcárcel, M. A., Méndez-Bértolo, C., & Pozo, M. A. (2009). Electrophysiological differences in the processing of affective information in words and pictures. *Cognitive, Affective, & Behavioral Neuroscience, 9*(2), 173–189.

Hung, S.-M., & Hsieh, P.-J. (2015). Syntactic processing in the absence of awareness and semantics. *Journal of Experimental Psychology: Human Perception and Performance, 41*(5), 1376–1384.

Hung, S.-M., & Hsieh, P.-J. (2021). Subliminal temporal integration of linguistic information under discontinuous flash suppression. *Journal of Vision, 21*(5), 27.

Hung, S.-M., Nieh, C.-H., & Hsieh, P.-J. (2016). Unconscious processing of facial attractiveness: Invisible attractive faces orient visual attention. *Scientific Reports, 6*, 37117.

Hung, S.-M., Wu, D.-A., & Shimojo, S. (2020). Task-induced attention load guides and gates unconscious semantic interference. *Nature Communications, 11*(1), 1–12.

Isenberg, N., Silbersweig, D., Engelien, A., Emmerich, S., Malavade, K., Beattie, B., … Stern, E. (1999). Linguistic threat activates the human amygdala. *Proceedings of the National Academy of Sciences, 96*(18), 10456–10459.

Jiang, Y., Costello, P., Fang, F., Huang, M., & He, S. (2006). A gender-and sexual orientation-dependent spatial attentional effect of invisible images. *Proceedings of the National Academy of Sciences, 103*(45), 17048–17052.

Jiang, Y., Costello, P., & He, S. (2007). Processing of invisible stimuli: Advantage of upright faces and recognizable words in overcoming interocular suppression. *Psychological Science, 18*(4), 349–355.

Kanwisher, N., Yin, C., & Wojciulik, E. (1999). Repetition blindness for pictures: Evidence for the rapid computation of abstract visual descriptions. In V. Coltheart (Ed.), *Fleeting memories: Cognition of brief visual stimuli* (pp. 119–150). Cambridge, MA: The MIT Press.

Karpinski, A., Briggs, J. C., & Yale, M. (2019). A direct replication: Unconscious arithmetic processing. *European Journal of Social Psychology, 49*(3), 637–644.

Karremans, J. C., Stroebe, W., & Claus, J. (2006). Beyond Vicary's fantasies: The impact of subliminal priming and brand choice. *Journal of Experimental Social Psychology, 42*(6), 792–798.

Killgore, W. D., Young, A. D., Femia, L. A., Bogorodzki, P., Rogowska, J., & Yurgelun-Todd, D. A. (2003). Cortical and limbic activation during viewing of high-versus low-calorie foods. *Neuroimage, 19*(4), 1381–1394.

Kuznetsova, A., Brockhoff, P. B., & Christensen, R. H. (2017). lmerTest package: Tests in linear mixed effects models. *Journal of Statistical Software, 82*, 1–26.

Larsen, R. J., Mercer, K. A., Balota, D. A., & Strube, M. J. (2008). Not all negative words slow down lexical decision and naming speed: Importance of word arousal. *Emotion, 8*(4), 445–452.

Lenth, R. V. (2016). Least-squares means: The R package lsmeans. *Journal of Statistical Software, 69*, 1–33.

Lin, S.-Y., & Yeh, S.-L. (2016). Interocular grouping without awareness. *Vision Research, 121*, 23–30.

Lo, S.-Y., & Yeh, S.-L. (2018). Does "a picture is worth 1000 words" apply to iconic Chinese words? Relationship of Chinese words and pictures. *Scientific Reports, 8*, 8289.

Ludwig, K., Sterzer, P., Kathmann, N., Franz, V. H., & Hesselmann, G. (2013). Learning to detect but not to grasp suppressed visual stimuli. *Neuropsychologia, 51*(13), 2930–2938.

Luo, Q., Holroyd, T., Jones, M., Hendler, T., & Blair, J. (2007). Neural dynamics for facial threat processing as revealed by gamma band synchronization using MEG. *Neuroimage, 34*(2), 839–847.

Mejova, Y., Abbar, S., & Haddadi, H. (2016). Fetishizing food in digital age:# foodporn around the world. *arXiv preprint*. arXiv:1603.00229v2.

Moors, P., Hesselmann, G., Wagemans, J., & van Ee, R. (2017). Continuous flash suppression: Stimulus fractionation rather than integration. *Trends in Cognitive Sciences, 21*(10), 719–721.

Morris, J. S., Öhman, A., & Dolan, R. J. (1998). Conscious and unconscious emotional learning in the human amygdala. *Nature, 393*(6684), 467–470.

Naccache, L., Gaillard, R., Adam, C., Hasboun, D., Clémenceau, S., Baulac, M., Dehaene, S., & Cohen, L. (2005). A direct intracranial record of emotions evoked by subliminal words. *Proceedings of the National Academy of Sciences, 102*(21), 7713–7717.

Pessoa, L., & Adolphs, R. (2010). Emotion processing and the amygdala: From a 'low road' to 'many roads' of evaluating biological significance. *Nature Reviews Neuroscience, 11*(11), 773–782.

Phelps, E. A., & LeDoux, J. E. (2005). Contributions of the amygdala to emotion processing: From animal models to human behavior. *Neuron, 48*(2), 175–187.

Pournaghdali, A., & Schwartz, B. L. (2020). Continuous flash suppression: Known and unknowns. *Psychonomic Bulletin & Review*, 1–33.

Prioli, S. C., & Kahan, T. A. (2015). Identifying words that emerge into consciousness: Effects of word valence and unconscious previewing. *Consciousness and Cognition, 35*, 88–97.

Rabagliati, H., Robertson, A., & Carmel, D. (2018). The importance of awareness for understanding language. *Journal of Experimental Psychology: General, 147*(2), 190–208.

Racine, S. E. (2018). Emotional ratings of high-and low-calorie food are differentially associated with cognitive restraint and dietary restriction. *Appetite, 121*, 302–308.

Robinson, M. D., Storbeck, J., Meier, B. P., & Kirkeby, B. S. (2004). Watch out! That could be dangerous: Valence-arousal interactions in evaluative processing. *Personality and Social Psychology Bulletin, 30*(11), 1472–1484.

Salomon, R., Galli, G., Łukowska, M., Faivre, N., Ruiz, J. B., & Blanke, O. (2016). An invisible touch: Body-related multisensory conflicts modulate visual consciousness. *Neuropsychologia, 88*, 131–139.

Sato, W., Sawada, R., Kubota, Y., Toichi, M., & Fushiki, T. (2016). Unconscious affective responses to food. *PLoS One, 11*(8).

Sato, W., Sawada, R., Kubota, Y., Toichi, M., & Fushiki, T. (2017). Homeostatic modulation on unconscious hedonic responses to food. *BMC Research Notes, 10*(1), 1–6.

Schmack, K., Burk, J., Haynes, J.-D., & Sterzer, P. (2016). Predicting subjective affective salience from cortical responses to invisible object stimuli. *Cerebral Cortex, 26*(8), 3453–3460.

Schupp, H. T., Stockburger, J., Codispoti, M., Junghöfer, M., Weike, A. I., & Hamm, A. O. (2007). Selective visual attention to emotion. *Journal of Neuroscience, 27*(5), 1082–1089.

Shang, J., Liu, Z., Yang, H., Wang, C., Zheng, L., Chen, W., & Liu, C. H. (2020). Perceptual advantage of animal facial attractiveness: Evidence from b-CFS and binocular rivalry. *Frontiers in Psychology, 11*, 1670.

Shanks, D. R. (2017). Regressive research: The pitfalls of post hoc data selection in the study of unconscious mental processes. *Psychonomic Bulletin & Review, 24*(3), 752–775.

Sheikh, U. A., Carreiras, M., & Soto, D. (2019). Decoding the meaning of unconsciously processed words using fMRI-based MVPA. *Neuroimage, 191*, 430–440.

Sheth, B. R., & Pham, T. (2008). How emotional arousal and valence influence access to awareness. *Vision Research, 48*(23–24), 2415–2424.

Sklar, A. Y., Goldstein, A. Y., Abir, Y., Goldstein, A., Dotsch, R., Todorov, A., & Hassin, R. R. (2021). Did you see it? Robust individual differences in the speed with which meaningful visual stimuli break suppression. *Cognition, 211*, Article 104638.

Sklar, A. Y., Levy, N., Goldstein, A., Mandel, R., Maril, A., & Hassin, R. R. (2012). Reading and doing arithmetic nonconsciously. *Proceedings of the National Academy of Sciences, 109*(48), 19614–19619.

Spence, C., Okajima, K., Cheok, A. D., Petit, O., & Michel, C. (2016). Eating with our eyes: From visual hunger to digital satiation. *Brain and Cognition, 110*, 53–63.

Stein, T. (2019). The breaking continuous flash suppression paradigm: Review, evaluation, and outlook. In G. Hesselmann (Ed.), *Transitions between consciousness and unconsciousness* (pp. 1–38). Routledge.

Stein, T., Awad, D., Gayet, S., & Peelen, M. V. (2018). Unconscious processing of facial dominance: The role of low-level factors in access to awareness. *Journal of Experimental Psychology: General, 147*(11), e1–e13.

Stein, T., Hebart, M. N., & Sterzer, P. (2011). Breaking continuous flash suppression: A new measure of unconscious processing during interocular suppression? *Frontiers in Human Neuroscience, 5*, 167.

Stojanoski, B., & Cusack, R. (2014). Time to wave good-bye to phase scrambling: Creating controlled scrambled images using diffeomorphic transformations. *Journal of Vision, 14*(12), 6.

Tan, J.-S., & Yeh, S.-L. (2015). Audiovisual integration facilitates unconscious visual scene processing. *Journal of Experimental Psychology: Human Perception and Performance, 41*(5), 1325–1335.

Tsuchiya, N., & Koch, C. (2005). Continuous flash suppression reduces negative afterimages. *Nature Neuroscience, 8*(8), 1096–1101.

Vetter, P., Badde, S., Phelps, E. A., & Carrasco, M. (2019). Emotional faces guide the eyes in the absence of awareness. *Elife, 8*, Article e43467.

Weng, X., Lin, Q., Ma, Y., Peng, Y., Hu, Y., Zhou, K., Shen, F., Wang, H., & Wang, Z. (2019). Effects of hunger on visual perception in binocular rivalry. *Frontiers in Psychology, 10*.

Werthmann, J., Roefs, A., Nederkoorn, C., Mogg, K., Bradley, B. P., & Jansen, A. (2011). Can (not) take my eyes off it: Attention bias for food in overweight participants. *Health Psychology, 30*(5), 561–569.

Yang, E., Zald, D. H., & Blake, R. (2007). Fearful expressions gain preferential access to awareness during continuous flash suppression. *Emotion, 7*(4), 882–886.

Yang, Y.-H., & Yeh, S.-L. (2018a). Can emotional content be extracted under interocular suppression? *PLoS One, 13*(11), Article e0206799.

Yang, Y.-H., & Yeh, S.-L. (2011). Accessing the meaning of invisible words. *Consciousness and Cognition, 20*(2), 223–233.

Yang, Y.-H., & Yeh, S.-L. (2014). Unmasking the dichoptic mask by sound: Spatial congruency matters. *Experimental Brain Research, 232*(4), 1109–1116.

Yang, Y.-H., & Yeh, S.-L. (2018b). Unconscious processing of facial expression as revealed by affective priming under continuous flash suppression. *Psychonomic Bulletin & Review, 25*(6), 2215–2223.

Yang, Y.-H., Zhou, J., Li, K.-A., Hung, T., Pegna, A. J., & Yeh, S.-L. (2017). Opposite ERP effects for conscious and unconscious semantic processing under continuous flash suppression. *Consciousness and Cognition, 54*, 114–128.

Yeh, S.-L., He, S., & Cavanagh, P. (2012). Semantic priming from crowded words. *Psychological Science, 23*(6), 608–616.