Acta Psychologica Sinica
2022, Vol. 54, No. 7, 725−735

https://doi.org/10.3724/SP.J.1041.2022.00725

A method for studying unconscious motion processing based on the camouflage principle

ZHAO Jiaxu, BAO Min
(*CAS Key Laboratory of Behavioral Science, Institute of Psychology, Chinese Academy of Sciences, Beijing* 100101, *China*)
(*Department of Psychology, University of Chinese Academy of Sciences, Beijing* 100049, *China*)

Abstract

The present study introduces a new continuous flash suppression (CFS) paradigm. We used the principle of alpha blending to keep the color of the target stimuli always consistent with that of the masking stimuli. We randomly recruited eight participants. Their dominant eyes were presented with the regular CFS masks. Meanwhile the non-dominant eyes were presented with ten spatially non-overlapping squares moving at a constant velocity. The results showed that the CFS masks in this new paradigm could efficiently block the conscious processing of the multiple moving targets. Furthermore, the breakthrough rate was the lowest when the colors of the targets were fully consistent with the colors of the CFS masks. This suggests that the new paradigm is more powerful than the traditional CFS paradigm in masking dynamic stimuli. Compared with the prevalent idea of modifying CFS masks, our method is believed to have broader applicability. Therefore, we recommend the new paradigm a useful tool for future investigations of unconscious visual motion information processing.

Key words continuous flash suppression, unconscious processing, motion, camouflage, alpha blending

1 Introduction

Vision is one of the most important senses of humans. Through vision, we can perceive the size, brightness, color and motion of objects, and obtain all kinds of information which is important to survival. In most vision studies, stimuli are consciously perceived. Yet given the limited perceptual ability of the visual system, not all stimuli can enter consciousness and be perceived. In order to study visual stimuli that fail to reach consciousness, contemporary vision research has developed some methods for studying unconscious visual processing (Kim & Blake, 2005). One common method is the continuous flash suppression (CFS) paradigm (Tsuchiya & Koch, 2005).

In the regular CFS paradigm, dynamic or high contrast image sequences are presented to one eye as masks (see the Mondrian pattern sequences in Figure 1). While in the opposite eye, a static or lower contrast target is presented. Because of the masking from the CFS stimuli, the target is usually rendered invisible for a few seconds, and processed at an unconscious level (Tsuchiya & Koch, 2005; Faivre et al., 2014). As the masking gradually weakens, the target can breakthrough the masks and become visible. To date, the CFS paradigm has been used in many studies on unconscious visual processing. Here are a few examples. Some researchers used facial images with different features or emotional valences as targets to explore unconscious processing of faces. For example, Jiang et al. (2007) used upright and inverted faces as targets, and found that upright faces can breakthrough the masks faster than inverted faces. Yang et al. (2007) reported the same phenomenon using fearful, neutral, and happy faces as targets. They also found that fearful faces broke the masks faster than neutral or happy faces. Even when only cropped images of eyes (instead of the full faces) were presented as targets, they still obtained similar results. Using threatening, positive and neutral faces as targets, Capitão et al. (2014) found that the target of a threatening face was more likely to breakthrough the CFS in anxiety patients. Moreover, other researchers have used words as targets to explore whether people can complete semantic processing of words without being aware of them. For example, Jiang et al. (2007) used Chinese words and Hebrew words as targets, and found that targets of particitants' native language broke masks faster. In contrast, Heyman and Moors (2014) used English words and Pseudo-words as targets, and found no significant difference in breakthrough time. And in Lang et al. (2018), participants judged the correlation between the targets of a series of paired Chinese words in the CFS paradigm. The results again showed that the participants could not complete semantic processing in the unconscious condition. In addition, a CFS paradigm was used to explore whether the participant's performance still abode by the law of closure and continuity in Gestalt principles under unconscious conditions (Moors et al., 2016).

While the CFS paradigm is widely used, researchers have been unremittingly improving the CFS paradigm according to their own research purposes. For example, unlike the use of 2D targets in most CFS studies, Korisky et al. (2018) have tried

Received Date: September 15, 2021
This work was supported by the National Natural Science Foundation of China (31871104, 31830037), the Key Laboratory of behavioral sciences of the Chinese Academy of Sciences (Y5CX052003), and the undergraduate scientific research fund of the Institute of Psychology, the Chinese Academy of Sciences.
Corresponding author: BAO Min, E-mail: baom@psych.ac.cn
The original article is in Chinese, translated by Eastrans and proofread by the author. The Chinese version shall always prevail in case of any discrepancy or inconsistency between the Chinese version and its English translation. We thank to DONG Xue and HE Xin for their helping translate a part of the manuscript.

using 3D real-life objects. They discovered that 3D objects in real life can also be masked and processed unconsciously in the CFS paradigm. Cha et al. (2019) compared the masking effect of different variants of CFS masks, including normal, pointwise, scrambled pointwise images of objects and scenes. They found that the object images had stronger masking effect than scene images, and the pointwise images showed stronger masking effect than the scrambled pointwise images. Moreover, Han et al. (2021) replaced the common Mondrian pattern sequences with upright faces, inverted faces and reconstructed faces, and tested the masking effect on faces or grating patches presented to the other eye. They found that the masking effect was stronger when masks and targets were of the same type.

Nevertheless, so far, most studies using the CFS paradigm have used static targets (or in situ moving gratings, such as Hong & Blake, 2009; Veto et al., 2018). Only Moors et al. (2014) have investigated the masking effect of the CFS paradigm when the target is spatially moving. In Moors et al.'s (2014) work, the target was a red circle moving in six different directions (horizontal left/right and right/left, vertical up/down and down/up, diagonal bottom-left/top-right and top-left/bottom-right) with many squares of the same size as the target serving as the masks. They presented the masks in two ways. One was called moving Mondrian mask (MMM), in which the squares in the masks were randomly assigned to six moving directions and moved frame by frame. Thus, there was always one square that moved in the same direction as the target. The other condition was the regular CFS condition, in which the squares randomly changed their positions on the screen every 100 ms. Moors et al. (2014) found that MMM was more effective in masking the moving targets than the regular CFS paradigm, especially when the velocity of MMM was close to that of the targets. Their finding supports the general view that the closer properties of masks and targets, the stronger the masking effect. However, Moors et al.'s (2014) method does not apply to the situations in which the targets are multiple moving points or have complex movement patterns. In principle, their method is highly dependent on the presentation of masks that share the moving pattern with the targets. Future work is still needed to understand how to overcome the above limitations and how to render the moving targets invisible.

The present study proposes a novel paradigm that in which the targets are presented in a special way while the CFS masks remain to be the regular version. The purpose of this study is to investigate whether the modified CFS paradigm is more advantageous in masking multiple moving targets. Previous studies have shown that the masking effect is stronger if the features of the masks and targets bear a stronger resemblance (Han et al., 2021; Mei et al., 2015; Moors et al., 2014; Stein et al., 2011; Valuch, 2021). Based on the principle of camouflage, this study explores whether the CFS masking effect can be stronger if the colors of the targets and the masks are more consistent. Just like animals such as chameleons, they rely on camouflage to keep their chromatic appearances consistent with that of the complex environment, so as not to be detected by predators. Therefore, we named this paradigm the "chameleon" paradigm. Our expectation is that breaking the mask is most difficult in the "chameleon" condition when the colors of the targets were fully consistent with those of the CFS masks. Because the essential of this method is not to change the CFS masks by incorporating the targets' motion information, but to camouflage the motion of targets by real-time manipulating the targets' colors that are independent of motion. This ensures that the consciously perceived CFS masks do not contain or reveal any motion information of the targets, which is the key advantage of the present method.

2 Method

2.1 Partcipants

We used G*Power to determine the required sample size for the experiment. The results indicated that at least seven subjects were needed to obtain a moderate effect size ($f = 0.40$, $\alpha = 0.05$, power = 0.95) for repeated measure analysis of variance (ANOVA) (Faul et al., 2007). Therefore, eight participants were recruited from several universities in Beijing, China, including four males and four females (age range 21 to 26 years, mean age: 23 ± 1.66 years). The participants had corrected to normal vision, and no parachromatoblepsia or achromatopsia. None of them had participated in similar experiments before. All have provided written informed consent before the experiment and were paid after the experiment.

2.2 Materials

Stimuli were shown on a 27.2-inch ACI2725 ASUS VG278HE monitor (1920 × 1080 pixels; refresh rate 120 Hz; gamma-corrected; mean luminance: 40 cd/m^2). The display was calibrated using a Photo Research PR-655 spectrophotometer. The background color of the screen was gray (RGB: 128 128 128) and the central fixation was red. Meanwhile, we used the NVIDIA 3D Vision 2 device to conduct the experiments and present the stimuli. The device consisted of a NVIDIA GPU that supports 3D stereo technology, a certified monitor, the active shutter glasses (NVIDIA 3D Vision 2 P1431) and an infrared transmitter, and was supported by the Windows system, NVIDIA 3D stereo driver and the four-buffer OpenGL stereo technology. Participants watched the screen through active shutter glasses to ensure different visual input for the two eyes.

The experimental stimuli, including the CFS masks and target stimuli, were programmed using MATLAB (The MathWorks, Natick, MA) and Psychtoolbox-3 (Brainard, 1997). The CFS stimuli consisted of 60 Mondrian pattern images which were created by drawing rectangles of random color and size (8° × 8°, flashing at 10 Hz, the RGB and color-space values of the rectangular patches are shown in Table 1). The target stimuli were ten spatially non-overlapping squares (1° × 1°) that were randomly positioned within an 8° × 8° area. The squares continued to move upwards or downwards at a constant velocity of 12 pixels/s for one second, after which ten new squares were generated and moved in the same direction as the previous squares. In each trial, the target was presented for 10 s. Four kinds of target, including a "chameleon" condition and three control conditions, were designed according to their color consistency with the CFS stimuli. In Condition 1 ("chameleon" condition), the colors of the squares for each presentation frame were identical to those of the pixels in the corresponding positions of the CFS stimuli. In Condition 2, the colors of the squares in each frame were inconsistent with those of the pixels in the corresponding positions of the CFS stimuli. In Condition 3, the colors of the squares were always the same as the first frame of CFS masks. And in Condition 4, five of the squares were black (RGB: 0 0 0) and the other five were white (RGB: 255 255 255). The target stimuli in Condition 1-3 were generated using alpha blending algorithm. Specifically, to produce the target of each frame in Condition 1, we first created a 4-layer (RGBA) image array, where the RGB layers were the same as those of the CFS masks of this frame. The A layer described the transparency of the image. The values of A layer matrix in the positions corresponding to the ten squares were 255 and the other values in the matrix were 0. Therefore, the image drawn from this image array contained ten squares whose colors were the same as those in the corresponding positions in the CFS stimuli, while the color of the rest image area was identical to the background. The way to make target in Condition 2 was similar except that another pre-made CFS masks was adopted. Thus, the colors of the ten squares were different from those in the corresponding positions of the CFS masks which was simultaneously presented to the other eye. As for Condition 3, just the first frame of CFS masks was used to produce the target image. Generally, only in Condition 1 were the colors of target stimuli identical to those of the CFS stimuli in the other eye. Compared with Condition 1, the target stimuli in Condition 2 remained flashing, but the colors were different from those of the CFS masks. The target stimuli in Condition 3 were not flashing, but their colors were the same as those of the first frame of CFS masks. The target in Condition 4 was also not flashing and the squares were achromatic. In each condition, the contrasts of CFS stimuli and the target were always 100%.

Table 1
RGB values and CIE color space values of Mondrian patterned rectangles

Color category	R	G	B	x	y	u’	v’
1	255	0	0	0.6422	0.3436	0.4400	0.5286
2	255	255	0	0.4296	0.5339	0.2010	0.5621
3	0	255	0	0.3174	0.6321	0.1276	0.5717
4	0	0	255	0.2000	0.2325	0.1484	0.3882
5	255	0	128	0.3507	0.1634	0.3293	0.3453
6	0	255	255	0.2277	0.3174	0.1433	0.4496
7	255	128	0	0.4689	0.4952	0.2343	0.5568
8	128	0	255	0.1518	0.0496	0.1845	0.1356
9	0	128	255	0.2479	0.1073	0.2615	0.2546
10	128	0	128	0.2837	0.1231	0.2902	0.2833

Note. R, G, and B represent the colors of the red, green, and blue channels in the color system. X, y are color space values of CIE 1931 color space, and u', v' are color space values of CIE 1960 color space.

2.3 Procedures

The experiment was conducted in a dark room. The participants viewed the display at a distance of 90 cm. A chinrest was used to help minimize head movement.

We first measured the eye dominance of each participant in a pre-test task. The procedures were referred to that of the screen task in Dong et al. (2022). The CFS stimuli were randomly presented to one eye and the target was presented to the other eye. The target was a black frame (1.2 ° × 1.2 °) with a black bar (0.4° × 4 pixels) in the center, presented foveally. Participants were required to judge the relative position of the black bar to the fixation and made the corresponding key-press response (above: “↑”; below: “↓”; left: “←”; right: “→”) once the target broke into their awareness. The pre-test task consisted of three blocks, each including 80 trials. The central bar of the target could be above or below the fixation, or to the left or right of the fixation. The different targets were randomly presented to each eye during the experiments. Each trial of the task started with the display of a red central fixation point for 800 ms. Then the CFS stimuli appeared in one eye and kept flashing until the end of the trial. After a random duration (100 ms/200 ms/300 ms/400 ms), a target would be presented to the other eye. A trial terminated once a response was made. Then the target disappeared and the presentation of CFS stimuli ended after another 600 ms. If no response was detected, the target would disappear after 2 s, and the CFS stimuli disappeared after an extra 600 ms (see Figure 1). We calculated the breakthrough rate of target in each eye by dividing the number of correct responses by the total trial count for each eye-of-origin condition. The eye with higher breakthrough rate was regarded as dominant eye. It took about 15 mins to complete the pre-test task.

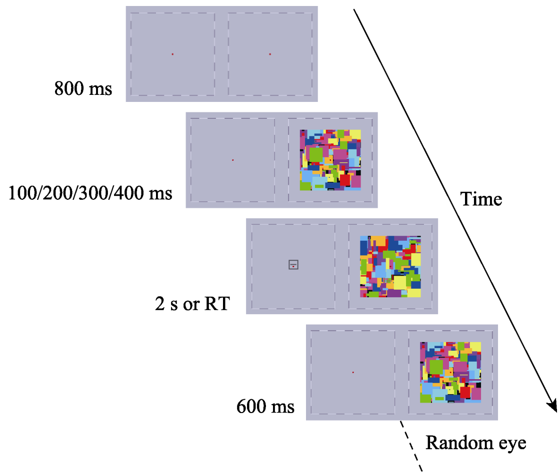

Figure 1. Design of pre-test task. The CFS stimuli were randomly presented to one eye, with target in the other eye. RT denotes reaction time.

In the formal experiments, the CFS stimuli were always presented to the dominant eye that determined in the pre-test task, while the target stimuli were presented to the non-dominant eye. However, if the experimenter failed to discern the participants’ dominant eye using the pre-test task, one of the eyes would be randomly selected for presenting the CFS masks. Before the formal experiment, the experimenter would explain the procedures in detail and asked the participants to practice several trials to ensure that they have fully understood the task. The formal experiment consisted of 14 blocks. Each block contained 16 trials, with four trials for each target condition. The targets moved up in two of the trials and moved down in the other two trials. Each trial began with the presentation of CFS stimuli in the dominant eye for 500 ms or 1500 ms. Then the target (moving up or down) of one of the four conditions appeared in the non-dominant eye, while the CFS stimuli were still flashing in the other eye. The participants were asked to judge the motion direction of the target stimuli once it broke into awareness and made the corresponding key-press response (up: “↑”; down: “↓”). Participants’ response and the reaction time of each trial were recorded. The target stimuli would disappear immediately after the participants responded (correct: breakthrough; error: no breakthrough), and the CFS stimuli would keep on presenting for another 500 ms. Otherwise, if the participants did not perceive the target (no breakthrough), both stimuli would be displayed for 10 s. There would be a 1-s interval between every two trials where only the gray background was displayed (see Figure 2). After each block, the message of "Take a break! You still have N blocks to complete. Press the 'Space' to continue." would be displayed on the screen to remind participants to have a break. It took about 35 mins to complete the formal experiment.

2.4 Data analysis

A within-subject experimental design was employed, with the target conditions and test phases (the testing blocks were equally divided into four phases) as independent variables. Though all the target stimuli moved either up and down at a certain speed in each condition, their appearances varied depending on the degree of color consistency with the CFS stimuli. The dependent variable was the breakthrough rate. A breakthrough means that the suppression on target from CFS stimuli is broken and target can be consciously perceived.

To avoid the influence of instable task performance at the beginning of the experiment, the results from the first two blocks were eliminated and only the results of the last 12 blocks were included in the analysis. The data analysis process was as follows: first, the breakthrough rates of each condition and each block were calculated for every participant. In order to investigate how the breakthrough rate changed over time, the 12 blocks were equally divided into four test phases. Then, a 4 (Condition 1-4) × 4 (Test phase 1-4) repeated measures ANOVA was performed on the breakthrough rates to examine whether there were any differences between target conditions and test phases. Besides, we also analyzed the average reaction time of the breakthrough trials in each condition.

3 Results

3.1 The change tendency of breakthrough rate

Only the data of the last 12 blocks were included in the analysis. First, the 12 blocks were equally divided into four test phases. Then, we calculated the average breakthrough rate for each test phase under each condition, and drew a line chart to show the trend of the breakthrough rate of each participant (see Figure 3). As shown in Figure 3, we found that for most participants the breakthrough rate under Condition 1 was apparently lower than under the other three conditions. Meanwhile, there was no obvious difference between the other three conditions. We also drew the line chart of the average breakthrough rate across all the participants (see Figure 4). We found that the breakthrough rate of Condition 1 was also lower than the other three conditions throughout the experiment, and there seemed to be little difference between the other three conditions.

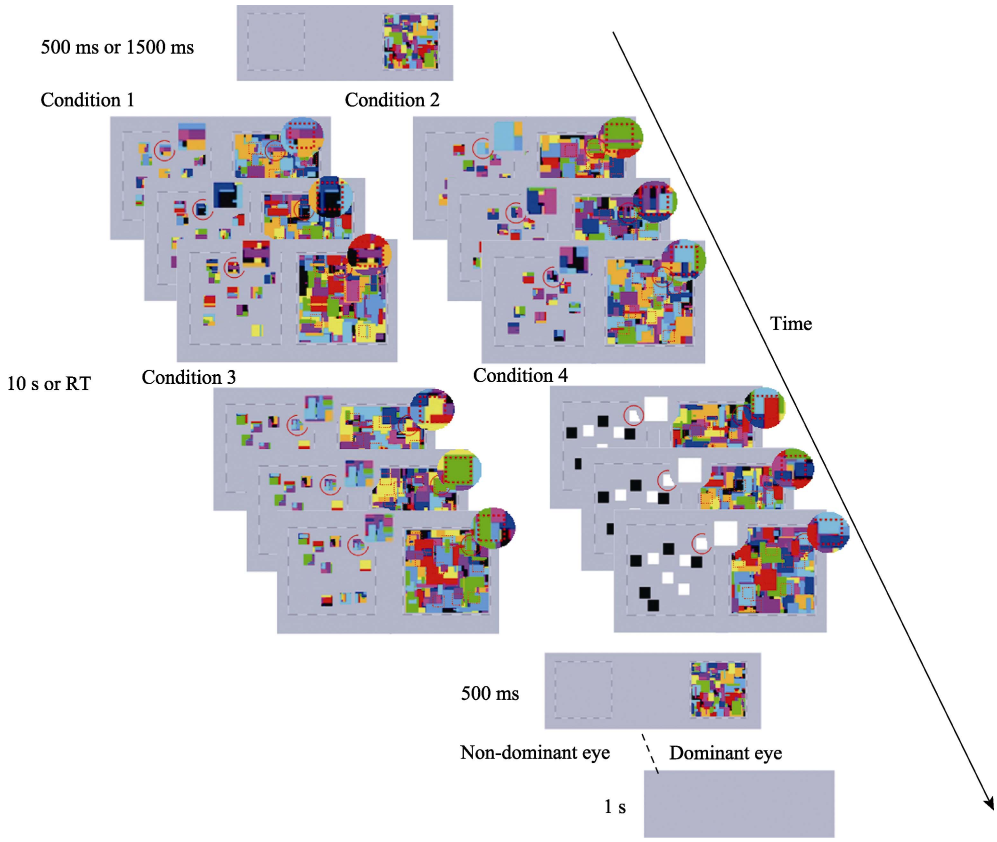

Figure 2. Design of formal experiment. The dominant eye was presented with the regular CFS masks, while the non-dominant eye was presented with the target which were ten spatially non-overlapping squares and moved either upwards or downwards at a constant velocity. The red circles and the large squares in the upper right corner in the pictures of non-dominant eye, as well as the red circles, the large circles in the upper right corner and the red dotted square lines in the pictures of dominant eye were used only for illustration, none of them appeared in the formal experiment. The large squares in the upper right corner in the pictures of non-dominant eye were the magnified images of the small squares in the red circles. It can be found that only the colors of the large squares in Condition 1 in the pictures of non-dominant eye were identical to the colors in the dotted square lines in the pictures of dominant eye. Besides, the other nine dashed squares in the CFS masks correspond to the areas of the other nine squares in the non-dominant eye. RT denotes reaction time.

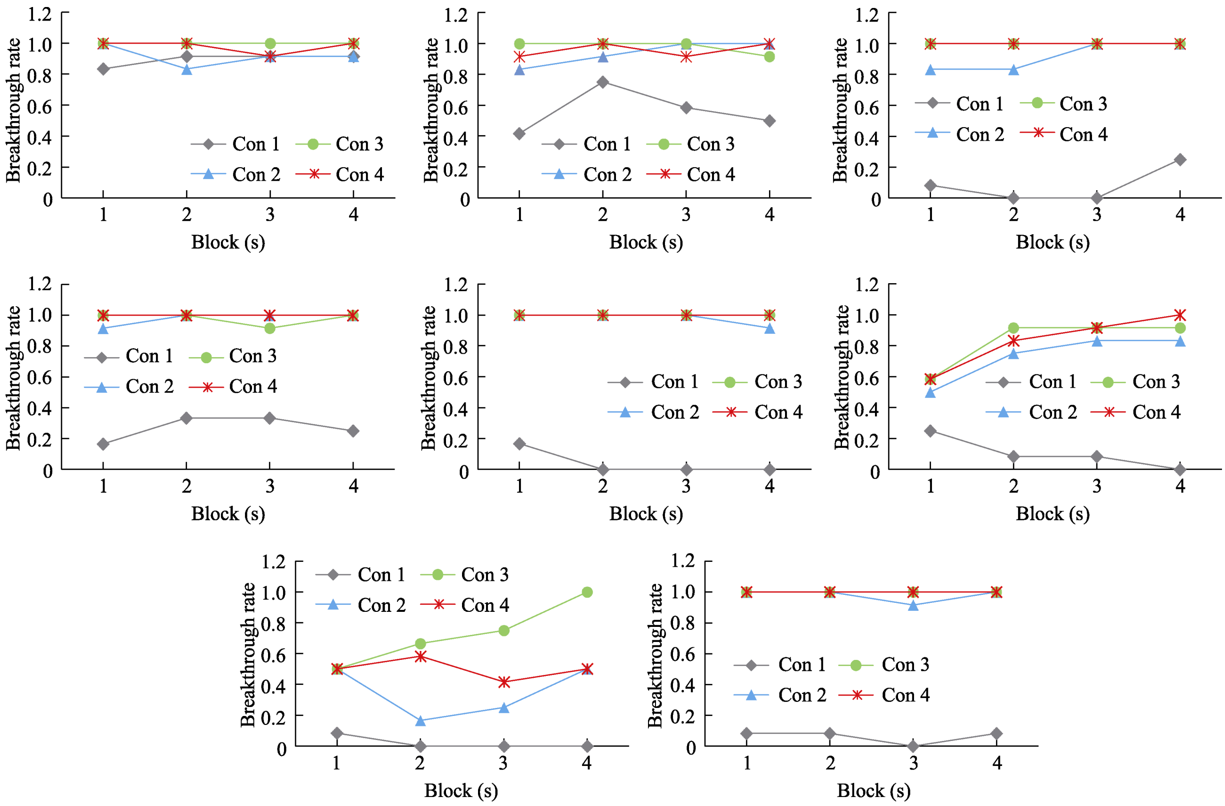

Figure 3. Breakthrough rate plotted individually. Some data points are covered by other data points because the data of some conditions were equal. Con, condition.

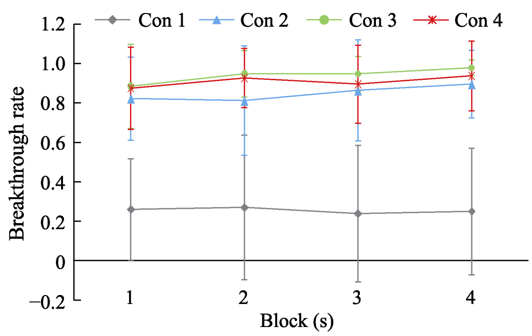

Figure 4. Grand average of breakthrough rate. The error bar indicated 1 *SD*. Con, condition.

3.2 Repeated measures analysis of variance

We further investigated the effect of condition and test phase on the breakthrough rate using a two-factor (Condition × Test phase) repeated analysis of variance. The results showed that the main effect of Condition was significant ($F(1, 1.201) = 32.38$, $p < 0.001$, $\eta^2 = 0.82$, corrected by Greenhouse-Geisser corrected), but the main effect of Test phase was not significant ($F(1, 3) = 1.62$, $p = 0.215$, $\eta^2 = 0.19$). The interaction between them was not significant ($F(1, 3.038) = 0.72$, $p = 0.552$, $\eta^2 = 0.09$, Greenhouse-Geisser corrected). These were consistent with our hypothesis that the differences in breakthrough rate were due to different conditions of target stimuli.

Only the main effect of Condition was significant, so we compared the difference of breakthrough rate between different conditions. The results of the post-hoc comparisons showed that the breakthrough rate of Condition 1 (0.26 ± 0.11) was significantly lower than those of the other three conditions (Condition 1 vs. Condition 2: $p = 0.008$, 95% CI [−1.011, −0.176]; Condition 1 vs. Condition 3: $p = 0.002$, 95% CI [−1.063, −0.307]; Condition 1 vs. Condition 4: $p = 0.003$, 95% CI [−1.053, −0.254]). Meanwhile, there was no significant difference between the other three conditions (Condition 2 (0.85 ± 0.08) vs. Condition 3 (0.94 ± 0.04): $p = 0.417$, 95% CI [−0.246, 0.064]; Condition 2 vs. Condition 4 (0.91 ± 0.06): $p = 0.057$, 95% CI [−1.121, 0.002]; Condition 3 vs. Condition 4: $p = 1.000$, 95% CI [−0.135, 0.073]).

3.3 Average reaction time in the breakthrough trials

Figure 5 showed the average reaction time in the breakthrough trials under different conditions. It should be pointed out here that reaction time was not indeed a suitable index in this study. That was because each trial in the study was limited to a maximum of 10 s, which automatically ended even if there was no breakthrough. Imagining that we extended the limit to 1 min or until the participant's response. Then the average reaction time of Condition 1 was bound to be much longer, even more than 10 s. That was why we did not use the reaction time as a valid indicator. We did not use the "appear until the participants respond" method because we found that Condition 1 was particularly effective for masking in the pre-test task. If we used this method, some participants' total duration of the experiment might be too long for them.

As Figure 5, although only the average reaction time in the breakthrough trials was shown, most of the participants had the longest reaction time in Condition 1. This further supported our finding that target stimuli were more difficult to break the mask when the target stimuli and the CFS stimuli were fully consistent in color.

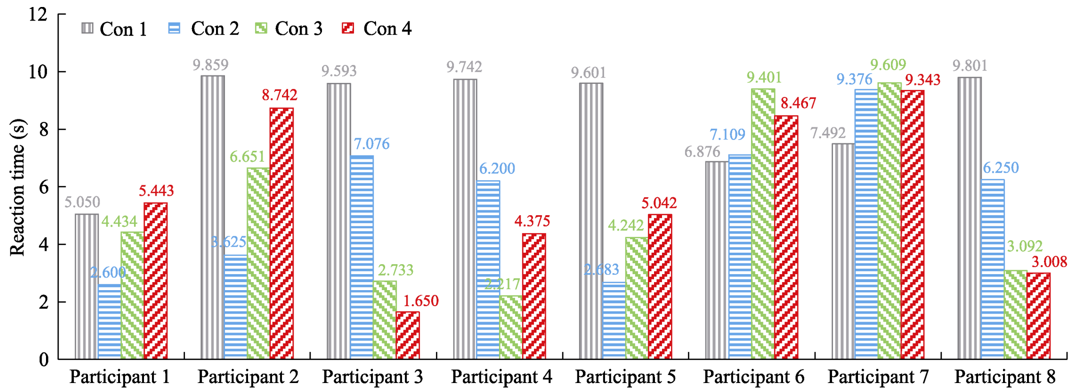

Figure 5. The average reaction time in the breakthrough trials under different conditions plotted individually. Con, condition.

4 Supplementary experiment

4.1 Purpose

From the results above, it could be concluded that in the "chameleon" paradigm, the moving targets could be well masked. We hoped that this paradigm could be applied to the study of unconscious motion processing. In order to figure out whether motion information masked under this paradigm can indeed be processed by the brain, we conducted a supplementary experiment. In the supplementary experiment, we compared the breakthrough rate of two types of target stimuli (with or without motion information) in the "chameleon" paradigm. If the target stimuli containing motion information were more likely to break the mask, it could be demonstrated that the motion information unconsciously processed "helped" the participants to complete the breakthrough, and that the brain could process the motion information unconsciously.

4.2 Participants

In order to compare the breakthrough rate of two types of target stimuli (with or without motion information) in the "chameleon" paradigm, we chose two participants (one male and one female) who had a high breakthrough rate under the "chameleon" condition (Condition 1) in the formal experiment to ensure that they have a certain number of breakthrough trials (Participant 2 and Participant 4 in Figure 3: Participant 1 also had a high breakthrough rate, but he could not participate due to the Covid-19 epidemic). The participants provided written informed consent before beginning the experiment and got paid after completing the experiment.

4.3 Materials and procedures

The materials and procedures of the supplementary experiment were similar to those of the formal experiment. On the basis of the formal experiment, Condition 1 was divided into two sub-conditions: Condition 1-moving and Condition 1-static. We equally divided the original trials in Condition 1 into two groups. One was the same as the formal experiment (Condition 1-moving), the targets were ten squares moving up/down in every frame, whose colors were fully consistent with those of the CFS stimuli. The targets in this group contained motion information. In the other group the motion information was removed (Condition 1-static): the targets were ten static squares, and their colors were also identical to those of the CFS stimuli. The other experimental conditions (Conditions 2, 3, and 4) were the same as the formal experiment. In each condition, the contrasts of CFS stimuli and the target were always 100%.

4.4 Data analysis and results

The data analysis of the supplementary experiment was the same as that of the formal experiment. Only the last 12 blocks were analyzed, and they were equally divided into four test phases. As shown in Figure 6, the breakthrough rate of the two participants in Condition 1-static was the lowest, obviously lower than that of Condition 1-moving. The only known difference between the two sub-conditions was whether the target stimuli contained motion information, so it could be inferred that the difference in breakthrough rate was caused by motion information. It was the brain's unconscious processing of motion

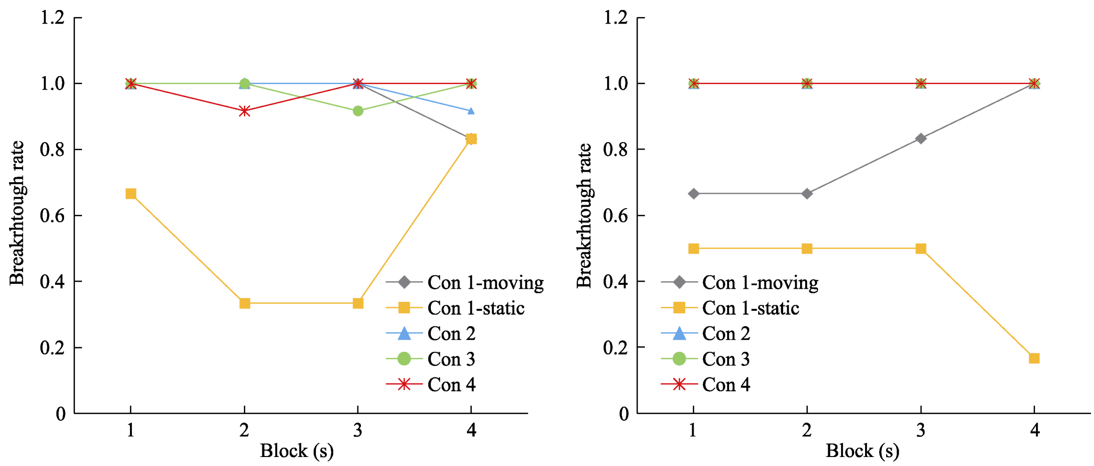

Figure 6. Breakthrough rate plotted individually in the supplementary experiment. Some data points are covered by other data points because some conditions overlap other conditions. Con, condition.

information that "helped" the participants break the mask of CFS stimuli. Therefore, the motion information in the "chameleon" paradigm can be unconsciously processed by the brain.

5 Discussion

This study introduced a novel paradigm, named "chameleon" to better maintain multiple moving target stimuli at an unconscious level. We found that the "chameleon" paradigm allowed the CFS masks to efficiently block the conscious processing of multiple moving targets. Meanwhile, when the colors of moving target stimuli were fully consistent with those of the CFS masks, the moving targets could be more efficiently masked and processed unconsciously.

Firstly, our results demonstrated that the CFS masks in the "chameleon" paradigm had a superior masking effect on multiple moving target stimuli. In contrast to the work of Moors et al. (2014), our paradigm enables masking of multiple rather than single moving targets. Many studies on motion perception involved multiple moving targets (e.g., optical flow motion, biological motion). Thus, our results further demonstrated the applicability of the CFS paradigm in exploring unconscious visual motion processing.

Secondly, as how camouflage works, when the colors of the CFS stimuli and the target stimuli were fully consistent, the masking effect of CFS was especially stronger, causing both lower breakthrough rate and longer reaction time in the breakthrough trials. Consistent with our findings, Moors et al. (2014) also showed that CFS was more effective when the masks were more similar to the targets. Moreover, by using the same and different colors of materials as masks and targets, Valuch (2021) proved that it was harder to break CFS when masks and targets had the same colors. A number of other studies have confirmed that feature similarity of dichoptic stimuli is important to the masking effect. That is, the more similar the CFS stimuli to the target stimuli, the better masking effect (e.g., Stein et al., 2011). However, unlike our method, the improvement of masking effect in all those studies is achieved by changing the features of CFS masks, which has certain limitations. For example, in Moors et al.'s study (2014), their pilot experiment showed that the moving target stimuli were not efficiently masked by using the regular CFS paradigm, unless the authors modified the CFS masks by incorporating the targets' motion information. This modified CFS paradigm (i.e. MMM) is competent for masking only a small number of moving target stimuli with a constant speed. When an experiment involves more complex target stimuli with multiple moving points or variable velocity (e.g., biological motion), it is impractical to exactly match the motion direction and speed of the masks with those of the targets. Valuch (2021) also found better masking effect of CFS by changing the color of the masks to a monochromatic consistent with the targets. When the targets are more complex, modifications of the masks would have to be more complex, too. If moving targets are multiple moving points or have complex movement patterns, the method of adding the moving features of targets to masks would be too complicated to achieve.

In this study, we used regular CFS and kept the features of CFS unchanged. What we changed was the appearance of the target stimuli based on the camouflage principle, which maximized the consistency of target stimuli and CFS stimuli in other features (e.g., color) except for motion information. Our method can easily realize masking of more complex moving targets. More important, it ensures that the eye presented with the CFS does not receive any visual motion information that should be masked. If the CFS masks contain the visual motion information that researchers are interested in, it may be difficult to interpret the experimental results. Because it is unclear whether the recorded behavioral results or neuroimaging signals depend on unconscious processing of motion information from the masked targets or on the conscious processing of motion information contained in the CFS. Yet the alpha blending algorithm we used was based on the camouflage principle. This kept the target stimuli consistent with the CFS stimuli in shape and colors on the one hand, and warranted that the motion information carried by the target stimuli was completely independent of the CFS stimuli on the other hand. Thus, the "chameleon" paradigm provides efficient CFS masking for all types of moving target stimuli. The results of the supplementary experiment also supported the notion that the brain had processed the masked motion information. Therefore, as compared with modifying CFS stimuli, our method has broader applicability in the study of unconscious motion processing.

One may argue that in our experiment the breakthrough of the target stimuli was not due to unconscious motion processing, but only occurred when binocular convergence failed. To address this issue, we gave the following two explanations. First, unlike many studies using the CFS paradigm, we used the shutter glasses (NVIDIA 3D Vision 2P1431) instead of stereoscopes to present dichoptic stimuli. One of its advantages over stereoscopes is that it effectively avoids the misalignement of eyes. The shutter glasses look like ordinary glasses. When wearing the shutter glasses, one can see the surroundings like wearing ordinary glasses, except for the CFS region on the screen where the stimulus presentation was dichoptic. The light from the surroundings is natural light and daily lighting, which is not subject to the workings of NVIDIA glasses (alternating between odd and even frames for each eye). Therefore, viewing the surroundings through the NVIDIA glasses is not much different than that through the ordinary glasses. This means that, except for the stimuli within the fusion frame on the screen where dichoptic presentations are controlled by NVIDIA glasses, everything else visible is normal (through the NVIDIA glasses). According to life experience, when we wear a pair of ordinary glasses to watch the surroundings, we will not have troubles on the convergence of the eyes. This also explains an important difference between using NVIDIA glasses and using stereoscopes. That is, the surroundings seen by the participants help their eyes converge as in everyday life. Second, even if to say the least, the failure to fully align the eyes leads to the breakthrough, it is difficult to explain the results of the supplementary experiment. The only difference between the "Condition 1-moving" and "Condition 1-stactic" in the supplemental experiment was whether the targets moved or not. For both conditions, the nature of the "chameleon" paradigm determined the difficulty of binocular convergence was exactly the same at any moment. Therefore, the binocular convergence should have a similar impact on these two conditions, and caused a similar breakthrough rate. However, the breakthrough rate of "Condition 1-moving" was higher than that of "Condition 1-stactic". This result is consistent with the explanation that unconscious motion information processing helps the targets to break the masking, but it is difficult to explain with the account of binocular convergence failure. Combining these two explanations, we believe that the breakthrough is unlikely to be caused by the failure of convergence, but is more likely to result from unconscious motion processing.

Previously, the CFS paradigm has often been used to study interocular suppression. A common control condition is to overlap the target stimuli onto the masking stimuli and present them monocularly. With this control, researchers can verify that any observed difference in suppression time in the CFS condition was due to interocular suppression (Wang et al., 2012). However, we cannot adopt this common control method to demonstrate that interocular suppression accounts for the masking effect in the “chameleon” paradigm. This is because the target stimuli and the corresponding masking stimuli were of exactly the same colors. If the two were overlapped with each other and presented monocularly, the participants would only see the CFS. Given that the purpose of this study is only to find a paradigm that can provide strong masking of the motion information for ease of exploring unconscious motion processing, whether the mechanism of masking in this paradigm depends on interocular suppression or not is unimportant. Moreover, interocular suppression is not the unique way to achieve unconscious processing. There are many other ways, such as visual crowding and backward masking, neither of these paradigms involves interocular suppression. Considering that the CFS paradigm facilitates the study of longer-duration stimuli near the central visual field, we chose the regular CFS paradigm and improved it. As long as the motion information carried by the target stimuli is not easily perceived but processed unconsciously, the goal of the present study would be achieved. Future work may further examine whether interocular suppression plays a role in the masking.

In conclusion, the present study verified the masking effect of a modified CFS paradigm for moving target stimuli. For the first time, we examined the feasibility of using color consistency to improve the masking effect of CFS based on the camouflage principle. The results showed that the higher color consistency between the masks and moving targets, the stronger masking effect, and the breakthrough time was usually longer than 10 s. Importantly, the “chameleon” paradigm avoids the CFS masks from containing any motion information resembling the targets, thereby it ensures that the measurement of unconscious visual motion processing is exclusively from the target. Therefore, we recommend the “chameleon” paradigm a useful tool in the field of unconscious visual motion information processing.

Acknowledgments: We thank to DONG Xue for her contribution to the programming of the paradigm. Also, thanks to SANG Xiaohui and SONG Fangxing for their help in data collection.

References

Brainard, D. H. (1997). The psychophysics toolbox. *Spat Vis, 10*(4), 433–436.

Capitão, L., Underdown, S., Vile, S., Yang, E., Harmer, C., & Murphy, S. (2014). Anxiety increases breakthrough of threat stimuli in continuous flash suppression. *Emotion, 14*(6), 1027–1036.

Cha, O., Son, G., Chong, S., Tovar, D., & Blake, R. (2019). Novel procedure for generating continuous flash suppression: Seurat meets Mondrian. *Journal of Vision, 19*(14), 1–22.

Dong, X., Zhang, M., Dong, B., Jiang, Y., & Bao, M. (2022). Reward produces learning of a consciously inaccessible feature. *British Journal of Psychology, 113*(1), 49−67.

Faivre, N., Berthet, V., & Kouider, S. (2014). Sustained invisibility through crowding and continuous flash suppression: A comparative review. *Frontiers in Psychology, 5*, 475. http://10.3389/fpsyg.2014.00475

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.

Han, S., Alais, D., & Palmer, C. (2021). Dynamic face mask enhances continuous flash suppression. *Cognition, 206*, 104473. http://10.1016/j.cognition.2020.104473

Heyman, T., & Moors, P. (2014). Frequent words do not break continuous flash suppression differently from infrequent or nonexistent words: Implications for semantic processing of words in the absence of awareness. *PLoS One, 9*(8), e104719. http://10.1371/journal.pone.0104719

Hong, S. W., & Blake, R. (2009). Interocular suppression differentially affects achromatic and chromatic mechanisms. *Attention, Perception, & Psychophysics, 71*(2), 403–411.

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.

Kim, C-Y., & Blake, R. (2005). Psychophysical magic: Rrendering the visible ‘invisible’. *Trends in Cognitive Sciences, 9*(8), 381–388.

Korisky, U., Hirschhorn, R., & Mudrik, L. (2018). "Real-life" continuous flash suppression (CFS)-CFS with real-world objects using augmented reality goggles. *Behavior Research Methods, 51*(15), 2827–2839.

Lang, Y., Gao, T., & Tang, R. (2018). Continuous flash suppression inhibits semantic processing of Chinese characters with unawareness: An event–related potential study. *Journal of Behavioral & Brain Science, 8*(10), 574–586.

Mei, G., Dong, X., Dong, B., & Bao, M. (2015). Spontaneous recovery of effects of contrast adaptation without awareness. *Frontiers in Psychology, 6*, 1464. http://10.3389/fpsyg.2015.01464

Moors, P., Wagemans, J., & de-Wit, L. (2014). Moving stimuli are less effectively masked using traditional continuous flash suppression (CFS) compared to a moving mondrian mask (MMM): A test case for feature–selective suppression and retinotopic adaptation. *PLoS ONE, 9*(5), e98298. http://10.1371/journal.pone.0098298

Moors, P., Wagemans, J., van Ee, R., & de-Wit, L. (2016). No evidence for surface organization in Kanizsa configurations during continuous flash suppression. *Attention Perception & Psychophysics, 78*(3), 902–914.

Stein, T., Hebart, M., & Sterzer, P. (2011). Breaking continuous flash suppression: A new measure of unconscious processing during interocular suppression? *Frontiers in Human Neuroscience, 5*, 167. http://10.3389/fnhum.2011.00167

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

Valuch, C. (2021). Color can shorten breakthrough times in continuous flash suppression through increased salience and task relevance. *Vision, 5*(1), 13. https://doi.org/10.3390/vision5010013

Veto, P., Sch ü tz, I., & Einhäuser, W. (2018). Continuous flash suppression: Manual action affects eye movements but not the reported percept. *Journal of Vision, 18*(3), 1–10.

Wang, L., Weng, X., & He, S. (2012). Perceptual grouping without awareness: Superiority of kanizsa triangle in breaking interocular suppression. *Plos One, 7*(6), e40106. https://doi.org/10.1371/journal.pone.0040106

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