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Access to awareness is improved by affective learning

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Abstract: Increasing evidence has indicated that emotional information, and particularly threatening visual input, elicits faster behavioral responses than non-threatening stimuli. This superior processing of threatening information is also found under conditions where consciousness is absent. However, recent studies have found that faster unconscious detection of emotion-associated stimuli than neutral stimuli may be due to their unmatched physical characteristics, rather than by their emotional content. Thus, it is necessary to test whether emotional stimuli still have the processing advantage over neutral ones in unconscious conditions when low-level visual properties are matched. In order to investigate whether the unconsciously prioritized processing still occurred with emotion-associated stimuli which are physically identical, we used the conditioning paradigm to manipulate the affective significance of Gabor patches. Participants performed two challenging visual detection tasks under the breaking Continuous Flash Suppression (b-CFS) paradigm. In Experiment 1, differently oriented Gabor patches (45° and 135°) were used as materials. uring an initial learning phase, one oriented Gabor patch (e.g., 45°) was paired with an alarm sound (CS+), whereas the other was never paired with the alarm sound (CS−). The emotional rating indicated that negative emotion could be elicited by the alarm sound in the participants. The orientation of CS+ Gabor patches was counterbalanced across the participants. In the subsequent testing phase, the participants were required to discriminate the location of the Gabor patch relative to the central fixation as quickly and accurately as possible. In this phase, Gabor patches were suppressed by dynamic noise using b-CFS. The procedure in Experiment 2 was the same with that in Experiment 1, except that the color of the Gabor patches was also varied, between red and green. In Experiment 1, there was no difference in the accuracy between CS+ stimuli and CS− stimuli (99% vs. 99%). The suppression time results showed that the CS+ stimuli emerged from suppression faster than the CS− ones. In Experiment 2, there was no difference in the accuracy for different learning conditions. For the analysis of suppression time, the “learning effect” was computed to represent difference between experimental conditions and control condition. The integrated learning showed a significant learning effect, while there was no remarkable learning effect in orientation learning or in color learning condition. These findings revealed an unconscious processing advantage for aversive conditioned stimuli. Furthermore, the learning effect was specific to the conditioned stimuli and could not generalize to other similar objects. Taken together, this study provided further evidence for the optimized processing of affectively significant visual stimuli in unconscious conditions.

Keywords: affective learning; breaking Continuous Flash Suppression; unconscious processing

1 Introduction

Effectively extracting critical information from the environment is extremely meaningful to survival. Plenty of studies have found that, for human participants, emotional information has a significant processing advantage over neutral information (Hedger et al., 2015). This advantage was found in a wide range of cognitive processes, such as perception, attention and memory. A typical example of emotion affecting visual perception is that people were more sensitive in perceiving emotional information than neutral information (Phelps et al., 2006). Similarly, the distractors containing emotional information were more capable of capturing attention during visual search than neutral distractors, and therefore, reduced participants’ searching efficiency (Schmidt et al., 2014).

Recently, many studies in unconscious processing have also supported the perceptive processing advantage of emotional information. Yang et al. (2007) used a breaking continuous flash suppression (b-CFS) paradigm and found that, even when unconsciously presented, the fearful information overcame the suppression of noises and gained access to awareness more quickly than other information. In addition,

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other invisible emotional stimuli, such as angry faces (Gray et al., 2013) and angry gestures (Zhan et al., 2015) overcame suppression faster in the CFS. Moreover, the emotional stimuli suppressed by CFS could still capture attention and trigger emotional priming effects (Almeida et al., 2013; Jiang et al., 2006). Meanwhile, the results of these studies were supported by neural imaging evidence. A study using binocular rivalry found that suppressed fearful faces significantly evoked ventral amygdala (Lerner et al., 2012). Similarly, fearful eyes were found to evoke stronger activities in amygdala than happy eyes in a masking paradigm (Whalen et al., 2004). Most researchers believed that the advantage of emotional information was due to a subcortical pathway that bypassed the visual association cortex. This pathway is called the “low-level” pathway of visual processing. It starts from the superior colliculus, travels through the pulvinar nuclei and finally reaches the amygdala (Le Doux, 2000).

However, studies on the unconscious processing advantage of emotional information use emotional faces or emotional scenes as stimuli, which leads to controversial conclusions. It is possible that the processing advantage is not due to the emotional valence of the stimuli, but is due to the physical properties of the stimuli. For example, the sclera of fearful faces and neutral faces differ in size, which makes the luminance and contrast of the eye area to be different. The physical properties such as global or local luminance, contrast and spatial frequency have significant effects on binocular rivalry (Gayet et al., 2016), and thus should be rigorously controlled in experiments. Yang et al. (2007) found that fearful faces overcame suppression faster than neutral faces not only when they were presented unconsciously, but also when the faces were presented inversely. This result suggested that the processing advantage of fearful faces may have been caused by some low-level physical properties. In fact, in the field of attentional advantage of emotion, a study using a visual search task showed that angry faces popped out from the distractors with an advantage through parallel processing (Hansen & Hansen, 1988), whereas in a later study, the advantage disappeared when the low-level physical properties of the stimuli were controlled (Purcell et al., 1996). These findings further emphasized the importance of controlling the physical properties of the stimuli when investigating the visual processing advantage of emotion.

Recently, some researchers have tried to eliminate the effect of low-level physical properties. For example, Stein and Sterzer (2012) used emotional schematic faces and found that positive schematic faces overcame suppression faster than negative schematic faces in CFS. Although some properties such as color and luminance were matched in schematic stimuli, different emotional schematic faces still slightly differed in the curves of eyebrows, eyes and corners of the mouth. More critically, the same effect was found when the faces and emotional information were erased from the pictures leaving only the curves of the corners of the mouth. It suggested that the effect was not due to the emotional valence of the faces. Therefore, emotional schematic faces could not be used to examine the unconscious processing advantage of emotion.

To solve these problems, this study used an affective learning method in which the neutral stimuli with completely matched physical properties (differently oriented Gabor patches) were repetitively associated with unconditioned fearful stimuli (UCS) and became conditioned stimuli (CS) with emotional valence. Previous neural imaging studies showned the plasticity of early sensory cortices (e.g., visual and olfactory) that the activity or association in these areas was strengthened after affective learning (Damaraju et al., 2009; Li et al., 2008). These evidences of brain plasticity implied that affective learning could also ease perception. Furthermore, a study showed that affective learning could reduce the detecting threshold of Gabor patches (Padmala & Pessoa, 2008). Although a decreased threshold, i.e., an increased perceptive sensitivity, does not mean emotional stimuli can be processed unconsciously, we speculate that affective learning may facilitate unconscious emotional processing.

Therefore, the present study used Gabor patches with completely matched physical properties as stimuli. In Experiment 1 we used Gabor patches with different orientation. In Experiment 2 we used integrated Gabor patches with different colors and orientation. We combined the affective learning method and the b-CFS to investigate whether the stimuli had a processing advantage in unconscious condition after affective learning.

2 Experiment 1: Affective learning facilitates faster awareness of simple stimuli

Experiment 1 used aversive conditioning of affective learning. We associated Gabor patches which were neutral stimuli with an alarm sound which was an unconditioned stimulus (UCS) so that the neutral stimuli without emotional meaning became conditioned stimuli (CS) with emotional valence. Then we investigated whether the stimuli had an unconscious processing advantage after affective learning by examining whether the Gabor patches with affective learning overcame suppression faster than those without affective learning in CFS.

2.1 Method

2.1.1 Participants

Twenty undergraduate students (12 females and 8 males, mean age = 22.5 years) were randomly selected. All the participants were right-handed, with normal or corrected-to-normal vision. Participants gave written consent before the experiment and received monetary compensation after the experiment.

2.1.2 Materials and equipment

Stimuli were presented on a 21 inch flat-screen CRT monitor Iiyama MA203DT Vision Master Pro 513, with a resolution of 1 024 × 768 and a refresh rate of 85 Hz. The experiment was programmed using Matlab r2008b and Psychophysics Toolbox-3 (Brainard, 1997; Pelli, 1997). During the experiment, the participants were required to place their lower jaw on a chin rest so that the distance between their eyes and the screen was kept 52 cm. A stereoscope was used to project the left half of the screen to the left eye and the right half of the screen to the right eye.

The background of the screen was grey. Two 13.5° × 13.5° stimuli areas were presented on the left and right halves of the screen respectively. The border of the area was 1.7° wide. The stimuli areas were 12.7° away from the center of the screen. Each area had a 0.5° × 0.5° black “+” as the central fixation point. The UCS was a 100 dB alarm sound (https://www.ee.columbia.edu/~dpwe/sounds/) processed using Goldwave. The alarm sound was presented 1 s after the Gabor patch. The sound was presented for 1 s including 10 ms of fade-in and fade-out. The CS was a Gabor patch with a diameter of 4.3°. The Gabor patch was rotated 45° or 135° to create the CS+ and the CS−. Whether the 45° oriented Gabor patch was the CS+ was counterbalanced between subjects. For half of the participants, the 45° oriented Gabor patch was used as CS+ and the 135° oriented Gabor patch as CS−, and the opposite for the other half of the participants.

2.1.3 Design and procedure

Experiment 1 used an one-factor two-level within-subject design. The independent variable was the learning conditions: CS+ condition in which Gabor patches were presented followed by an alarm sound (UCS), and CS− condition in which Gabor patches were presented without the alarm sound. The 45° or 135° oriented Gabor patches were used as the CS+ or the CS−, and were counterbalanced between subjects. The dependent variable was suppression time (ST), defined as the time between the onset of the picture and the time participants perceived the picture. The ST was negatively related to the stimuli’s velocity of gaining access to awareness. The larger the ST was, the slower the stimuli gained access to awareness.

Experiment 1 included a learning phase and a testing phase. After the experiment, the participants were asked to rate the emotional level of the alarm sound (UCS) in terms of its unpleasantness, intensity and alertness. The response options ranged from 1 to 5, with higher scores indicating stronger emotions.

The learning phase used the classical conditioning paradigm. There were 80 trials in total. The trials were divided into two blocks, each consisting of 40 trials. A 45° or 135° oriented Gabor patch was presented in each trial. Equal numbers of trials were assigned to the 45° or 135° condition. The procedure of each trial is illustrated in Figure 1. First, the central fixation points were presented for 800–1 200 ms, followed by Gabor patches for 200 ms. And finally, the central fixation points were presented for 1 s, during which the participants in the CS+ condition would hear an unpleasant alarm sound (UCS), whereas the participants in the CS− condition would not hear any sound.

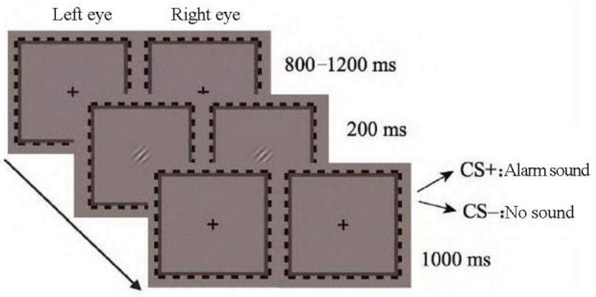

Figure 1 Procedure of the learning phase. In the learning phase, identical Gabor patches were presented to both eyes of the participants. One oriented Gabor patch was followed by an alarm sound (CS+) whereas the other was not (CS−). Participants did not need to respond in the learning phase.

The testing phase consisted of 120 trials in total, which were divided into three blocks of 40 trials. The target stimuli were randomly presented to the left or right eye in 60 trials respectively. Before the experiment, the participants had 20 practice trials to get familiar with the task and procedure. In the testing phase, the b-CFS paradigm was used to suppress the visual stimuli from access to awareness (Jiang et al., 2007). The procedure of each trial is illustrated in Figure 2. First, the central fixation points were presented for 800–1 200 ms. Then a standard dynamic mask (Mondrian mask) was presented to one of the eyes and a Gabor patch was presented to the other eye. Whether the mask was presented to the left or right eye was randomized. The target stimulus was presented at a random location inside the square area.

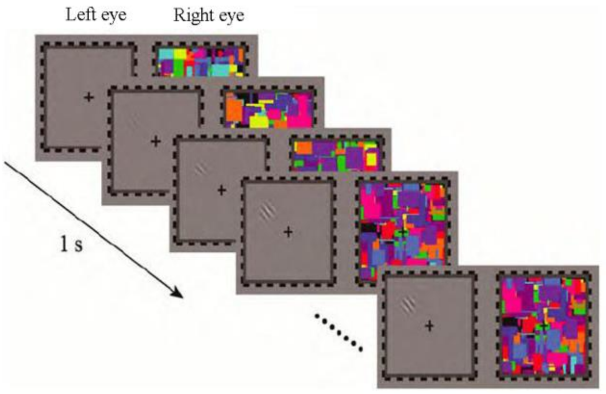

Figure 2 Procedure of the testing phase. In the testing phase, a Gabor patch was presented to one of the eyes of the participants, and a dynamic Mondrian mask was presented to the other eye to suppress the target stimuli from awareness.

Its contrast gradually increased from 0 to 100% within 1 s. The participants were required to judge the location of the target stimulus. They were instructed to press "←" if the target was on the left of the "+", and press "→" if the target was on the right of the "+". The next trial began after the participants responded or if the participants did not respond in 12 s.

2.2 Results and analysis

2.2.1 Emotional ratings of the sound and the stimuli

The results of the emotional ratings showed that the alarm sound (UCS) triggered a negative emotion to a certain extent. One sample t-tests showed that the mean score on "unpleasantness" was significantly different from 1 (1 represents not unpleasant at all): $M = 2.35$, $SD = 1.27$, $t(19) = 4.76$, $p < 0.001$; the mean score on "intensity" was significantly different from 2: $M = 2.85$, $SD = 0.93$, $t(19) = 4.07$, $p = 0.001$; the mean score on "alertness" was significantly different from 2.5: $M = 3.1$, $SD = 1.25$, $t(19) = 2.14$, $p < 0.05$.

The last 8 participants also rated how much they liked the CS+ and the CS− on a 9-point scale (1 represents they dislike the stimulus very much and 9 represents they like the stimulus very much). The score of the CS+ ($M = 4.25$, $SD = 1.04$) was significantly different from the score of the CS− ($M = 5.5$, $SD = 0.76$), $t(7) = -2.38$, $p < 0.05$, $d = 0.84$.

2.2.2 Accuracy

The accuracy of the 20 participants was almost 100%. The accuracy in the CS+ condition ($M = 0.99$, $SD = 0.03$) was not significantly different from that in the CS− condition ($M = 0.99$, $SD = 0.02$), $t(19) = 0.806$, $p > 0.05$.

2.2.3 Suppression time (ST)

The ST that was longer than 10 s was beyond three standard deviations of the mean and was excluded. Jiang et al. (2007) suggested that, if the target stimuli did not overcome suppression in 10 s, the final ST may involve some unknown factors. Overall, 1.2% of the data were excluded. The ST of the CS+ and the CS− was statistically analyzed. The results wasere plotted in Figure 3. The mean ST of the CS+ was 1.96, with a standard deviation of 0.72; the mean ST of the CS− was 2.26, with a standard deviation of 0.96. The CS+ gained access to awareness significantly faster than the CS−, $t(19) = -2.82$, $p < 0.05$, $d = 0.63$.

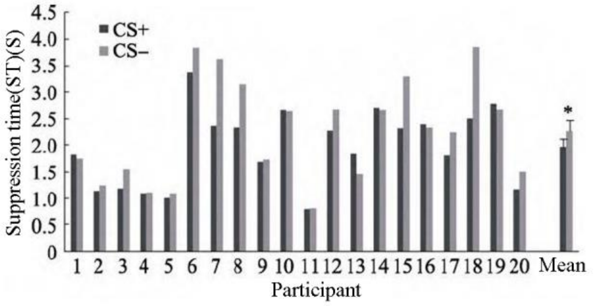

Figure 3 Result of Experiment 1. STs of the CS+ and the CS− for each participant and the mean STs across participants. Error bars represent standard errors (SE).

3 Experiment 2: Affective learning facilitates faster awareness of complex stimuli

In Experiment 1, the participants associated differently oriented Gabor patches with emotions. The results showed that Gabor patches followed by an alarm sound overcame suppression and were perceived faster in an unconscious task than those without alarm sounds. Orientation is a simple visual property. The question is whether this unconscious processing advantage still exists if the conditioned stimulus is more complex, such as an integrated stimulus with two dimensions (color and orientation). And if the advantage still exists, whether the advantage is specific to that integrated stimulus, or is generalized to other stimuli that share one identical property with the integrated stimulus. Therefore, Experiment 2 used the same method as in Experiment 1 except that, instead of using simple one-dimensional stimuli which only varied in orientation, the materials in Experiment 2 were complex two-dimensional stimuli which varied in color and orientation. The purpose of Experiment 2 was to investigate the unconscious processing advantage of complex stimuli after affective learning.

3.1 Method

3.1.1 Participants

Twenty undergraduate students (11 females and 9 males, mean age = 22.23 years) participated in the experiment. All the participants were right-handed, with normal or corrected-to-normal vision. The participants gave written consent before the experiment and received monetary compensation after the experiment.

3.1.2 Materials and equipment

In Experiment 2, the background of the screen was black. The central fixation point was a grey "+". Unlike Experiment 1 in which there were only two types of stimuli, in Experiment 2 we used four types of stimuli: 45° oriented red, 45° oriented green, 135° oriented red and 135° oriented green Gabor patches. A pilot study showed that the STs of the four types of stimuli were not significantly different, $F(3, 57) = 0.91$, $p > 0.05$. Other materials and equipment were the same as in Experiment 1.

3.1.3 Design and procedure

The experiment used a 2 (orientation: 45° and 135°) × 2 (color: red and green) within-subject design. The independent variable consisted of four conditions: the integrated learning condition (Gabor patches with a specific orientation and color and was followed by an alarm sound), the orientation learning condition (Gabor patches that had the same orientation as the stimuli in the integrated learning condition), the color learning condition (Gabor patches that had the same color as the stimuli in the integrated learning condition) and the control condition (Gabor patches that had different orientations and colors from the stimuli in the integrated learning condition). The dependent variable was suppression time (ST). The correspondence between Gabor patches with different orientations and colors and learning types was counterbalanced between subjects.

The procedure of Experiment 2 was the same as Experiment 1 (see Figures 1 and 2) except for the materials. Experiment 2 consisted of a learning phase and a testing phase. In Experiment 2, only one of the four types of Gabor patches was presented followed by an alarm sound. The other Gabor patches were presented without the alarm sound.

The learning phase consisted of 160 trials, which were divided into four blocks of 40 trials. Each of the four types of Gabor patches was presented 40 times in a random order. One of the Gabor patches (CS+) was followed by an alarm sound (UCS) 1 s after it disappeared. Which Gabor patch was followed by the alarm sound was counterbalanced between subjects: for 5 participants, the 45 ° oriented red Gabor patch was followed by the alarm sound; for another 5 participants, the 45 ° oriented green Gabor patch was followed by the alarm sound; for another 5 participants, the 135 ° oriented red Gabor patch was followed by the alarm sound; for the rest 5 participants, the 135 ° oriented green Gabor patch was followed by the alarm sound. The rest of the Gabor patches were not followed by the alarm sound. The testing phase consisted of 240 trials in total, which were divided into 6 blocks of 40 trials.

3.2 Results and analysis

3.2.1 Accuracy

The accuracy of the 20 participants was almost 100%. The accuracy in the integrated learning condition (M = 0.997, SD = 0.01), in the orientation learning condition (M = 0.997, SD = 0.01), in the color learning condition (M = 0.998, SD = 0.01) and in the control condition (M = 0.995, SD = 0.01) was not significantly different.

3.2.2 Suppression time (ST)

The ST that wereas longer than 10 s was beyond three standard deviations of the mean and was excluded. Less than 1% of the data were excluded. We used the “learning effect” to compare different learning conditions. It was calculated as follows:

Learning effect = learning condition (ST) − control condition (ST). We obtained the effect sizes of the three learning types. One sample t-tests were used to examine whether the effects of the three learning conditions were significant (comparing to 0). The effect of integrated learning was significant, $M = -0.067$, $SD = 0.12$, $t(19) = -2.557$, $p < 0.05$; the effect of orientation learning was not significant, $M = -0.021$, $SD = 0.13$, $t(19) = -0.701$, $p > 0.05$; the effect of color learning was not significant, $M = 0.031$, $SD = 0.11$, $t(19) = -1.27$, $p > 0.05$.

4 Discussion

The current study used the affective learning method to match the physical properties of emotional stimuli, so that possible confounding variables in previous studies were excluded. Therefore, we were able to investigate whether the stimuli containing only emotional valence information had an unconscious processing advantage. In a b-CFS paradigm, we found that conscious learning could affect the unconscious processing. Stimuli overcame suppression faster in the CFS paradigm after affective learning. In addition, we found that the unconscious processing advantage of emotion did not only apply to simple stimuli with different orientations, but also applied to complex integrated stimuli. It also suggested that color and orientation were bound during unconscious processing.

The results of our study clearly showed that affective learning could facilitate the unconscious processing of stimuli that were originally neutral. This finding is consistent with previous findings that affective learning facilitates attention and perception. The stimuli with affective learning (CS+) showed an attentional advantage in a detection task (Armony & Dolan, 2002) and in a visual search task (Notebaert et al., 2011). For example, Notebaert et al. (2011) found that although the CS+ did not capture attention, it prioritized attention comparing to the CS−. Moreover, Padmala and Pessoa (2008) found that when the near-threshold stimuli were paired with an electric shock, they were more likely to be detected by the participants. It suggested that affective learning could reduce participants’ perceptive threshold of the stimuli. In addition to the emotional valence obtained from affective learning, arousal may also affect perception. Woods et al. (2013) found that the participants with higher arousal level were visually more sensitive. In the present study, we found that affective learning facilitated the access of CS+ to awareness. It suggested that affective learning could enhance perceptive processing and furthermore, emotional association could enhance unconscious information processing.

The result of this study is consistent with the previous studies that emotional stimuli have an unconscious processing advantage. Most of the studies used the masking paradigm or the CFS paradigm to create unconscious conditions. These studies found that emotional stimuli could be processed under unconscious conditions. For example, they could trigger the emotional priming effect (Almeida et al., 2013). Also, they could evoke stronger activity in amygdala than neutral stimuli. However, the emotional stimuli used in previous studies were mostly angry faces (Gray et al., 2013), which had emotional valence. In the current study, we used the CFS paradigm and found that the processing advantage could also be obtained through affective learning. Critically, the current study controlled the physical properties of emotional stimuli. As mentioned in the introduction, the luminance, contrast and spatial frequency of the eye area are difficult to match for facial stimuli. Nevertheless, our study used differently oriented Gabor patches that were conditioned through affective learning and counterbalanced between subjects to ensure their luminance, contrast and spatial frequency were completed matched.

We found that the unconscious processing advantage not only applied to simple stimuli, but also applied to complex stimuli that contained both orientation and color features. Furthermore, this advantage was specific to stimuli that were identical to the learning stimuli (identical orientation and color) and did not transfer to similar objects (only identical in one dimension). It is worth noting that this result is consistent with the results of Rajimehr (2004) which investigated unconscious orientation adaptation. In that study, Gabor patches with high spatial frequency were used so that the orientation of the Gabor patches was perceptually invisible. The result showed that aftereffects were produced only when the adapting and test stimuli were identical. No orientation aftereffects were observed when the adapting and test stimuli had identical orientation but different colors. These results suggested that under unconscious conditions, participants processed an integration of orientation and color, instead of processing orientation or color separately. These results also supported the unconscious binding hypothesis (Lin & He, 2009).

The pasticity of the visual cortex may contribute to the shorter suppression time of stimuli with affective learning. In addition to the study mentioned in the introduction (Padmala & Pessoa, 2008), another study also found that affective learning enhanced functional connectivity in early visual cortex (Damaraju et al., 2009). It suggests that, affective learning influences the activity in both amygdala, which is well-known, and early visual cortex. Similarly, auditory cortical plasticity was found in the study examining the effect of auditory classical conditioning (Bieszczad & Weinberger, 2010). The widely existing plasticity implies that the unconscious processing advantage obtained through affective learning may relate to the activity of early visual cortex.

The present study found stimuli could obtain an unconscious processing advantage through affective learning. Its neural mechanism may relate to the amygdala. Jiang and He (2006) used the CFS paradigm and found that under unconscious conditions, fearful faces evoked stronger activity in amygdala comparing to neutral faces. Moreover, under unconscious conditions, the stimuli with affective learning evoked stronger activity in amygdala than those without affective learning (Morris et al., 1998). Recent studies found that amygdala not only responded to emotional stimuli, but also played an important role in affective learning, especially in the acquisition of fear responses (Knight et al., 2005). Therefore, the result of the present study that the stimuli with affective learning overcame suppression faster may be because those stimuli activated the amygdala under unconscious conditions and the visual cortex had a functional change. However, it is not clear whether the amygdala and the early visual cortex are activated simultaneously and functionally connected during affective learning.

Although the present study found an effect of affective learning on unconscious information processing, it is not clear how long this effect will last. Will it last for minutes, a day, or even a week? Future studies are needed to address this question. We found complex objects could also obtain unconscious processing advantage through affective learning. However, those integrated stimuli only had features on two dimensions. Further studies are needed to examine whether the objects that are more complex, such as faces, can obtain unconscious processing advantage through affective learning.

5 Conclusions

(1) The neutral stimuli with affective learning had an unconscious processing advantage over those without affective learning.

(2) This advantage not only applied to simple one-dimensional stimuli, but also applied to complex two-dimensional stimuli. Moreover, this advantage did not generalize to objects that were similar to the conditioned stimuli.

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