Unconscious processing of facial expression as revealed by affective priming under continuous flash suppression

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Abstract

Whether emotional information from facial expressions can be processed unconsciously is still controversial; this debate is partially due to ambiguities in distinguishing the unconscious–conscious boundary and to possible contributions from low-level (rather than emotional) properties. To avoid these possible confounding factors, we adopted an affective-priming paradigm with the continuous flash suppression (CFS) method in order to render an emotional face invisible. After presenting an invisible face (prime) with either positive or negative valence under CFS, a visible word (target) with an emotionally congruent or incongruent valence was presented. The participants were required to judge the emotional valence (positive or negative) of the target. The face prime was presented for either a short (200 ms, Exp. 1) or a long (1,000 ms, Exp. 2) duration in order to test whether the priming effect would vary with the prime duration. The consistent priming effects across the two priming durations showed that, as compared to their incongruent counterparts, congruent facial expressions can facilitate emotional judgments of subsequent words. These results suggest that the emotional information from facial expressions can be processed unconsciously.

Keywords Unconscious processing · Affective priming · Facial expression · Continuous flash suppression

When different visual stimuli are presented to each of the two eyes simultaneously, the incompatible inputs of the two eyes rival each other in access to visual awareness (Alais & Blake, 2005). Therefore, an observer tends to perceive only one of the two stimuli, with the other stimulus being interocularly suppressed to be invisible and thus removed from awareness. It has been proposed that this reciprocal competition occurs in multiple stages (Blake & Logothetis, 2002; Sengpiel, Blakemore, & Harrad, 1995) and that whether the suppressed information can still be processed along the information-processing pathway depends on the level of processing the stimulus requires.

Most findings suggest that low-level but not high-level information can be processed under interocular suppression. For example, the low-level properties of suppressed images, such as spatial frequency (Blake & Fox, 1974) and orientation (Wade & Wenderoth, 1978), can induce aftereffects on subsequent targets. On the other hand, high-level information, such

as object representation (Tong, Nakayama, Vaughan, & Kanwisher, 1998) and semantic information (Blake, 1988; Zimba & Blake, 1983), does not seem to survive interocular suppression. Zimba and Blake adopted the semantic-priming paradigm with binocular rivalry and found that a priming effect occurred when the prime was in the dominant phase, but not when it was in the suppressed phase. Consistent with this result, both monkey electrophysiology (Sheinberg & Logothetis, 1997) and human fMRI (Tong et al., 1998) have shown that the activities of the neural system are correlated with conscious perception of the object; there were no associated neural activities for images that were not consciously perceived (i.e., that were suppressed) during binocular rivalry. These findings contributed to the proposition that high-level information under suppression is “out of sight, out of mind” (Zimba & Blake, 1983).

Tsuchiya and Koch (2005) developed yet another type of interocular suppression technique called *continuous flash suppression* (CFS), in which the to-be-tested stimulus is presented to one eye, which is strongly suppressed by a train of dynamically high-contrast masks that are presented to the other eye. By manipulating the contrasts of the to-be-tested stimulus and masks, the suppression time can be controlled in order to sustain suppression from seconds to minutes

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(Tsuchiya & Koch, 2005). This longer suppression time provides an opportunity to test whether invisible stimuli can be integrated into higher-level information (Lin & He, 2009; Mudrik, Breska, Lamy, & Deouell, 2011; Mudrik, Faivre, & Koch, 2014) or can be represented as fractionated collections of low-level features (Moors, Hesselmann, Wagemans, & van Ee, 2017; Zadbood, Lee, & Blake, 2011), just as in the findings of conventional binocular rivalry.

An intensely debated issue over the past decade has been whether the emotional information from facial expressions can be processed under CFS (Gray, Adams, Hedger, Newton, & Garner, 2013; Jiang & He, 2006; Stein & Sterzer, 2012; Sterzer, Hilgenfeldt, Freudenberg, Bermpohl, & Adli, 2011; Yang, Zald, & Blake, 2007). For example, Yang et al. (2007) showed that a fearful face was faster in breaking CFS (b-CFS, hereafter) to gain access to awareness than was a neutral or happy face, and that this was true even for an observer with a lesioned amygdala (Tsuchiya, Moradi, Felsen, Yamazaki, & Adolphs, 2009). Other studies, however, have suggested that the observed preferential access of facial expressions is due to low-level properties such as contrast (Hedger, Adams, & Garner, 2015), local curvature (Stein & Sterzer, 2012), or spatial frequency (Stein, Seymour, Hebart, & Sterzer, 2014).

In addition to the discrepancies in results, explanations concerning the findings indexed by the measure of b-CFS time are still an issue for two reasons. First, if different classes of properties (e.g., contrast vs. emotional content) are contained within the to-be-tested stimulus (e.g., facial expression), it becomes difficult to distinguish which class has contributed to the difference in b-CFS times. For instance, in earlier studies that found preferential access of fearful faces into awareness, another critical factor was the salient eye-white region embedded in a fearful face (e.g., Yang et al., 2007). Thus, some questions remain unanswered, including whether the emotional content (i.e., fearful) or the eye-white region contributes to the difference in b-CFS times, and whether the eye-white region also represents the *emotional valence* of a fearful face (Whalen et al., 2004; Yang et al., 2007) or reflects only *low-level properties*, such as strong contrast in subareas (Gray et al., 2013; Hedger et al., 2015). Second, since b-CFS time actually measures how long it takes for a participant to detect the stimulus under CFS, the assumption that the b-CFS time can be fully attributed to unconscious processing *during* CFS is debatable. That is, the time interval after stimulus detection and before response is also included in the b-CFS time; thus, differences in that interval may have also contributed to different b-CFS times. Conservatively speaking, b-CFS time may involve a transition from unconscious to conscious processing; thus, it may not be unequivocal to explain b-CFS results as pertaining completely to unconscious processing (Gayet, Van der Stigchel, & Paffen, 2014; Stein, Hebart, & Sterzer, 2011; Stein & Sterzer, 2014).

In light of these considerations of b-CFS, it is important to use other measures to clarify which level of unconscious processing is probed under CFS (see Yang, Brascamp, Kang, & Blake, 2014, for a review).

In the present study, we adopted the affective-priming paradigm to test whether emotional content per se, rather than low-level properties, can be extracted under CFS. The prime was an emotional face that was rendered invisible under CFS, and the target was a visible emotional word, which the participants judged to have either positive or negative valence. The reaction times (RTs) for visible emotional word targets were measured. Since faces and words have minimal overlapping features, the possibility of perceptual facilitation could be ruled out. In addition, previous studies have shown that priming effects can transfer from positive to negative priming with lengthened prime duration under CFS (Barbot & Kouider, 2012), perhaps due to the overstimulation of perceptual signals, which induces a perceptual habituation effect (Barbot & Kouider, 2012). To test whether affective priming would also trigger negative priming given a longer prime duration, two prime durations were used—200 or 1,000 ms—to see whether the effect would vary as a function of prime duration.

Method

Participants

To determine the sample size, we calculated the average effect size from one relevant study that had tested congruent priming effects under CFS and backward masking (Almeida et al., 2014). In particular, we took their significant results of meaningful priming in CFS experiments only (i.e., Exp. 1a), in which they showed that primes with elongated shapes can facilitate responses to elongated tool targets. To achieve a power of $(1 - \beta) = .8$, the G*Power 3.1 (Faul, Erdfelder, Lang, & Buchner, 2007) toolbox showed that an estimated sample size of 22 participants would be required for an average standardized effect size of $d_z = 0.55^1$ with Type I error of $\alpha = .05$ (cf. Hesselmann, Darcy, Ludwig, & Sterzer, 2016).

Different groups of 22 and 20 participants took part in experiments with 200-ms and 1,000-ms prime durations, respectively. The participants were naïve as to the purpose of this experiment and had normal or corrected-to-normal vision. All of the participants gave informed consent according to the rules of the Ethics Committee of the Department of Psychology, National Taiwan University.

¹ The significant results of the CFS experiments in Almeida et al. (2014) showed that the mean priming effects and standard deviations (transferred from their *SEMs* and sample sizes) were 12 ± 20.78 (Exp. 1a, elongated tool prime) and 8 ± 15.59 (Exp. 1a, elongated animal prime), with standardized effect sizes of $d_z = 0.58$ and 0.51 , respectively.

Stimulus materials and apparatus

The stimuli were controlled by Psychophysics Toolbox 3.0 (Brainard, 1997) on Matlab 2012a (MathWorks, Natick, USA) and were presented on a 19-in. i-TECH IF900 CRT monitor ($1,024 \times 768$ resolution at 120-Hz refresh rate). In order to present the stimuli dichoptically, the participants viewed them through a pair of active shutter glasses (NVIDIA 3D Vision 2) that were synchronized with the refresh rate of the monitor via infrared emitter.

Two square contours ($13.8^\circ \times 13.8^\circ$, 0.18° thickness with white-noise pattern) were presented on a gray background (RGB values of [127, 127, 127]) for stable dichoptic fusion. Mondrian-like masks with 3,000 patches (random size: 0.02° to 1.09° ; random grayscale: 0–255) were presented in one fusion contour, and a face prime ($7.36^\circ \times 7.36^\circ$) was presented in another fusion contour. To render the face primes fully invisible, the masks were always presented to the participant's dominant eye. A visible word target ($5.52^\circ \times 2.76^\circ$) was presented binocularly in the center of both fusion contours without any masks.

The primes were faces selected from Ekman and Friesen (1976), with 12 posers (six females) producing 12 happy and 12 fearful facial expressions. The targets were two-character Chinese words selected from a set of words containing positive (12 words) and negative (12 words) meanings that were matched in usage frequency [mean frequency per million words: positive, 28.75; negative, 29.69; paired $t(11) = -0.283$, $p = .783$] and stroke numbers [mean stroke counts: positive, 24.92; negative, 26.00; paired $t(11) = -0.816$, $p = .432$]. During the affective-priming task, to prevent the abrupt stimulus onset from making the prime visible, the contrasts of the face primes were ramped up gradually from 0% to 25% within 200 and 1,000 ms, respectively. However, if the participants reported that they saw the prime during CFS after a trial, the contrast would be reduced by 1.5% to make the prime less visible in later trials. The contrast of the masks was kept at 100% throughout the experiment.

Design

A within-subjects design with Facial Expression (positive and negative) and Prime-Target Congruency (congruent and incongruent) as variables was conducted within each prime duration (200 ms and 1,000 ms). The congruent condition included a happy face prime with a positive word (e.g., 恭喜, “congratulations” in Chinese) or a fearful face prime with a negative word (e.g., 討厭, “dislike” in Chinese), and the incongruent condition included a happy face with a negative word or a fearful face with a positive word. Each Facial Expression $\times$ Prime-Target Congruency combination had 48 trials, so the four combinations led to 192 total trials.

Procedure

Each trial began when participants pressed the “Z” key on a keyboard with their left hand, followed by a 300-ms blank screen and then the 200-ms or 1,000-ms CFS stage, during which a face prime with either a happy or a fearful facial expression was suppressed by a dynamic mask that flashed at 10 Hz. After CFS, a word target with either a positive or a negative meaning was presented for 100 ms. The participants were asked to judge the emotional valence of the target by pressing “5” for positive or “6” for negative valence as quickly and accurately as possible with their right hand. If the participants saw any parts of the prime during CFS, they were instructed to press “7” to abandon the trial, and this response served as a subjective criterion of prime visibility for each trial (see Fig. 1a).

Upon completion of the priming task, the participants performed a two-alternative forced choice (2AFC) discrimination task to serve as an objective visibility check. Each face stimulus was repeated twice, with equal probability for positive and negative valences, to generate 48 total trials. The number of trials in this task was the same as for each condition in the priming task, which should provide reliable measurement. To prevent any distraction by the emotional meaning of the word targets, the procedure was the same as for the priming task, except without a target stimulus (Almeida, Mahon, & Caramazza, 2010; Hesselmann et al., 2016). The contrast of the face stimuli always ramped up gradually from 0% to 25% within either 200 or 1,000 ms. The participants were explicitly instructed that there were both happy and fearful faces to represent positive and negative valences, respectively. They were asked to judge the emotion valence of a face as correctly as possible without any time limits (see Fig. 1b).

Results

In both experiments, only trials fulfilling the following two criteria were included for further RT analyses: (a) RTs with correct responses to the word target's emotional judgment in which (b) the face prime was subjectively judged as being invisible. Outliers were also excluded if the RTs exceeded 2.5 standard deviations from the mean for each participant. We conducted an analysis of variance (ANOVA) on the accuracy and RT data with SPSS (IBM SPSS Statistics 20). Moreover, to ensure that the priming effect was not driven by individual face exemplars and participants, we also adopted linear mixed-effects analyses using the lme4 package (Bates, Maechler, Bolker, & Walker, 2015) for R (see Rabovsky, Stein, & Abdel Rahman, 2016; Stein, Kaiser, & Peelen, 2015, for similar analyses). The face prime exemplars and participants were treated as random intercepts in all of the models. In likelihood-ratio tests, a full model with all fixed

Fig. 1 Stimuli and procedure. **(a)** Affective-priming task: The trial was started by pressing a key, following which a fixation cross was presented for 300 ms. After this, a prime stimulus (shown here as a fearful face on the right side) was suppressed by dynamic masks that refreshed every 100 ms (10 Hz). Then a target (a two-character Chinese word, meaning “dislike” in this example) was presented for 100 ms, and the participants

were asked to judge the emotional valence of the words. Also, participants were instructed to press another key to abandon the trial if they saw any part of the prime during CFS in the emotional judgment frame. **(b)** Objective visibility check: The procedure was similar to that of the priming task, but without words being presented. The participants were asked to judge the emotional valence of the faces

effects and random effects was compared with a reduced model without the specific fixed effect in question (e.g., Facial Expression or Prime-Target Congruency) in order to test the main effect. The interaction effect was determined by comparing a full model with fixed effects, interaction(s), and random effects to a reduced model without the interaction term in question (e.g., Facial Expression $\times$ Prime-Target Congruency).

For the 2AFC objective visibility check, the accuracy data for each participant were submitted to binomial tests for comparison to chance level (50%), and the data for a given participant were excluded from further analysis if the accuracy was above chance (Hesselmans et al., 2016).

Prime duration of 200 ms

During the priming task, all participants reported that they did not see the prime, $M = 0$, $SD = 0$, and the mean accuracy of the objective visibility check was at chance level, $M = 48.38\%$, $SD = 6.77\%$, $t(21) = -1.10$, $p = .28$. On the other hand, the accuracy of emotional judgments of the word targets was high ($M = 95.43\%$, $SD = 4.11\%$). The accuracy was submitted to two-way repeated measures ANOVAs with the factors of Facial Expression and Prime-Target Congruency. Neither Facial Expression, $F(1, 21) = 0.329$, $p = .572$, $\eta_p^2 = .015$, nor Prime-Target Congruency, $F(1, 21) = 0.086$, $p = .772$,

$\eta_p^2 = .004$, had a main effect. There was a significant interaction between Facial Expression and Prime-Target Congruency, $F(1, 21) = 4.459$, $p = .047$, $\eta_p^2 = .175$. For the negative face prime, the simple main effect of Prime-Target Congruency revealed a tendency ($p = .057$) for the congruent trials ($M = 96.78\%$, $SD = 4.20\%$) to have higher accuracy than the incongruent trials ($M = 94.22\%$, $SD = 5.93\%$), according to Tukey's HSD post-hoc test.

The ANOVA for correct RTs of emotional judgments showed a main effect of Prime-Target Congruency, $F(1, 21) = 5.355$, $p = .031$, $\eta_p^2 = .203$, indicating that emotion judgments were faster for congruent prime-target pairs than for their incongruent counterparts. Neither Facial Expression, $F(1, 21) = 0.048$, $p = .829$, $\eta_p^2 = .002$, nor the interaction, $F(1, 21) = .750$, $p = .396$; $\eta_p^2 = .034$, was significant. See Fig. 2 for all RT results.

In the linear mixed-effects analysis, the full model had significantly different results from the reduced model without the fixed effect of Prime-Target Congruency, $\chi^2(1) = 5.543$, $p = .019$, whereas neither the main effect of Facial Expression, $\chi^2(1) = 0.021$, $p = .885$, nor the interaction, $\chi^2(1) = 2.509$, $p = .113$, was significant.

Prime duration of 1,000 ms

One participant was excluded because that participant's accuracy in the objective visibility check was higher than chance in a binomial test, 78.50%, $p < .001$. Aside from this participant, the rate of seeing the face primes during CFS was low, $M = 0.68\%$, $SD = 1.54\%$, and the mean accuracy in the objective visibility check was at chance level, $M = 50.26\%$, $SD = 4.06\%$, $t(18) = 0.27$, $p = .79$. Also, the accuracy of emotional judgments of the word targets was high, $M = 96.41\%$, $SD = 2.64\%$, but neither Prime-Target Congruency, $F(1, 18) = 1.761$, $p = .201$, $\eta_p^2 = .089$, nor Facial Expression, $F(1, 18)$

$= 0.601$, $p = .448$, $\eta_p^2 = .032$, nor their interaction, $F(1, 21) = 1.103$, $p = .307$, $\eta_p^2 = .058$, had a significant effect.

The correct RTs also were submitted to two-way repeated measures ANOVAs. The results again showed a significant main effect of Prime-Target Congruency, $F(1, 18) = 7.083$, $p = .016$, $\eta_p^2 = .282$, indicating that congruent prime-target pairs were judged faster than their incongruent counterparts. Neither Facial Expression, $F(1, 18) = 0.018$, $p = .895$, $\eta_p^2 = .001$, nor the interaction, $F(1, 18) = 0.007$, $p = .936$, $\eta_p^2 < .001$, was significant.

The linear mixed-effects analysis comparing the full model with the reduced model without the fixed effect of Prime-Target Congruency was marginally significant, $\chi^2(1) = 3.426$, $p = .064$, whereas neither the main effect of Facial Expression, $\chi^2(1) = 0.005$, $p = .941$, nor the interaction, $\chi^2(1) = 0.017$, $p = .897$, was significant.

Comparison between the 200-ms and 1,000-ms prime durations

To test whether the priming effect varied by prime duration, a three-way mixed-effects ANOVA with two within-subjects factors (Facial Expression and Prime-Target Congruency) and a between-subjects factor (prime duration) was conducted. The main effect of Prime-Target Congruency was significant, $F(1, 39) = 10.699$, $p = .002$, $\eta_p^2 = .215$, indicating that congruent trials were judged more quickly than incongruent trials. The main effect of prime duration was also significant, $F(1, 39) = 1,121.473$, $p < .001$, $\eta_p^2 = .966$, indicating that RTs with the 200-ms prime duration were faster than those with the 1,000-ms prime duration. We found no other significant effects ($ps > .489$). Consistent with the ANOVA analysis, the linear mixed-effects analysis also showed main effects of Prime-Target Congruency, $\chi^2(1) = 8.947$, $p = .003$, and prime duration, $\chi^2(1) = 8.557$, $p = .003$. There were no other significant effects ($ps > .190$).

Fig. 2 Mean reaction times in the affective-priming task for the 200-ms (left) and 1,000-ms (right) prime durations. The error bars represent one standard error of the mean

Discussion

We tested whether emotional content can be extracted under interocular suppression by adopting the affective-priming procedure with the CFS paradigm. The results revealed that a congruent meaning of facial expressions facilitated emotional judgments of subsequent words. This effect was found across both the short (200 ms, Exp. 1) and long (1,000 ms, Exp. 2) priming durations. These results cannot be explained by perceptual priming, since the face primes and word targets used here did not share similar perceptual properties. Together, the results suggest that emotional content can be extracted under CFS and influence the emotional judgment of subsequent targets.

Unlike Barbot and Kouider (2012), we did not find a negative priming effect when the prime duration was long (1,000 ms). However, the prime and target in the congruent condition of Barbot and Kouider's study differed only in size and viewpoint, whereas the face identity was kept the same; therefore, their results could partially be attributed to perceptual priming (Faivre, Berthet, & Kouider, 2014). Since we used very different types of primes and targets (faces and words), deeper processing up to the semantic level was needed. Therefore, instead of transferring from positive to negative priming with a longer prime duration, we still found a positive priming effect when the prime duration was 1,000 ms. This result suggests that affective-priming effects are more sustainable than perceptual-priming effects.

Another critical issue was how to assess and define unawareness of the face prime when the affective-priming effect occurred. How to measure *unconscious* processing under CFS has long been debated, as have the different pros and cons of subjective and objective measures (see Hesselmann, 2013; Sterzer, Stein, Ludwig, Rothkirch, & Hesselmann, 2014; Yang et al., 2014, for reviews). As was mentioned by Rothkirch and Hesselmann (2017), there is no generally accepted “gold standard” with which to measure awareness, so it is important to clarify the extent of the unconscious processing being measured. The trial-by-trial subjective reporting provided online monitoring and compatible situations during the experiment that directly reflected the visibility of the prime when the priming effect occurred. However, subjective reports are susceptible to the influence of arbitrary criteria and response bias (Hesselmann, 2013). Moreover, additional subjective reports during the main priming task may induce dual-task demands (Schmidt, Haberkamp, & Schmidt, 2011; Yang et al., 2014) and may cause different priming effects, due to the difference between attended and unattended primes (Ortells, Fox, Noguera, & Abad, 2003; Stein, Thoma, & Sterzer, 2015). To avoid this dual-task influence, we adopted single-stage response as our procedure for subjective reporting. Thus, we cannot exclude the possibility that the participants mainly focused on the main priming task and

ignored any subjective experience of the prime. Being aware of this possibility, we also conducted an objective visibility check after the main priming task, to assess the specific level of information (i.e., emotional content) driving the affective-priming effect in the priming task, and this check was based on the same experimental setup as the main experiment (see also Almeida et al., 2010; Almeida, Pajtas, Mahon, Nakayama, & Caramazza, 2013; Barbot & Kouider, 2012; Hesselmann et al., 2016). The fact that the participants had only chance-level performance in discriminating between positive and negative valences of the facial expressions thus suggests that the affective-priming effect in the main task was not driven by awareness of the face primes.

Over the last decade, the b-CFS task has served as a powerful tool to examine how efficiently a stimulus is processed under interocular suppression (see Gayet et al., 2014, for a review). However, although studies have shown that emotional expressions are processed differently from their neutral counterparts under interocular suppression (Gray et al., 2013; Hedger et al., 2015; Stein et al., 2014; Sterzer et al., 2011; Tsuchiya et al., 2009; Yang et al., 2007), it remains debated whether these results are attributable to low- or high-level factors. One major reason for this is that low-level properties are inevitably entangled when presenting diverse facial expressions (e.g., the eye-white region in a fearful face); thus, both emotional content and low-level properties are inevitably embedded in facial expression displays. Therefore, when adopting a direct measure of b-CFS time on a detection or localization task, low-level features such as contrast (Gray et al., 2013; Hedger et al., 2015) and spatial frequency (Stein et al., 2014) will covary with emotional content, which thus can not exclusively explain differential b-CFS results. Consequently, manipulating facial expressions alone cannot separate the contributions from high- versus low-level properties.

Instead, another, more convincing way to reveal high-level involvement is to additionally recruit factors that may interact with the affective evaluative processing of b-CFS. For example, Rabovsky et al. (2016) assigned either negative or positive affective knowledge to the same face across participants in order to rule out confounding from low-level properties. The results nevertheless showed no preferential access for faces through this affective-learning paradigm (see also Stein, Grubb, Bertrand, Suh, & Verosky, 2017). On the other hand, Sterzer et al. (2011) found that personal traits such as major depressive disorder mediated b-CFS times for happy and sad faces, and better depression treatment was correlated with longer suppression times for sad faces. Also, Schmack, Burk, Haynes, and Sterzer (2016) found that degree of spider phobia was correlated with b-CFS times of spider detection, and that the neural signals in the orbitofrontal and occipitotemporal cortices can also predict b-CFS times for spiders, as revealed by multivoxel pattern analysis. Such

results cannot be easily explained by low-level properties alone. Moreover, the same visual stimuli via fear conditioning with electric shocks revealed faster b-CFS times than their non-fear-conditioned counterparts (Gayet, Paffen, Belopolsky, Theeuwes, & Van der Stigchel, 2016). These studies reveal how to measure emotional meanings or affective responses without them being confounded with low-level properties in the b-CFS paradigm.

On the other hand, in the present study we adopted the affective-priming paradigm in order to indirectly measure the impact of emotional meaning from a face on the subsequent word. Nevertheless, whereas differential b-CFS times may be attributed to both low-level properties and emotional meaning, the advantage of the affective-priming effect is that the results can be more purely explained by emotional meaning alone. That is, the congruency effect on the emotional judgment of subsequent words should only be affected by emotional content and not by low-level properties from different facial expressions. Moreover, our results cannot be simply attributed to response priming, either. As was noted by previous studies, some unconscious affective-priming effects were found only when the primes interchangeably served as the targets; thus, the primes and targets corresponded to the same response in the congruent condition (Kiefer, Sim, & Wentura, 2015; Klauer & Musch, 2003). In this case, the congruency effect also coincides with the response. Our manipulations could exclude this possibility, since our face primes never served as targets throughout the experiment, and very different types of primes (i.e., faces) and targets (i.e., words) were used here. Without emotion contents being confounded with low-level properties and response priming, the present study showed that emotion meanings from facial expressions can facilitate emotional judgments of words.

This affective-priming effect of facial expressions is consistent with results from previous studies indicating that facial expressions are processed at different levels (e.g., the perceptual and appraisal levels) under CFS. For example, Adams, Gray, Garner, and Graf (2010) found that invisible facial expressions under CFS, such as anger, fearfulness, and happiness, can induce facial-expression aftereffects on a subsequent target face, indicating processing of the facial expression at the perceptual level (but see Yang, Hong, & Blake, 2010). Also, affective and personality (such as trustworthy, attractive, and interpersonally warm) judgments of a neutral face (Anderson, Siegel, White, & Barrett, 2012) and preference judgments of unrecognizable words (Almeida et al., 2013; but see Faivre, Berthet, & Kouider, 2012) can be affected by invisible facial expressions under CFS, indicating an appraisal level of processing facial expressions. Almeida et al. (2013) presented either an angry or a happy face as an invisible prime under CFS and asked the participants to rate their preference for a following Chinese character as the target. The participants rated a lower preference for an unfamiliar target when it was

preceded by an angry face. Nevertheless, note that the Chinese characters adopted in their case were unfamiliar neutral targets to their participants, and the characters were also meaningless in relation to the facial-expression prime. Therefore, the priming effect they found could directly reflect preferences for the invisible facial expressions per se. On the other hand, the Chinese characters adopted in our case would trigger emotional meanings for our participants, who were skillful Chinese readers. To achieve the affective-priming effect, one should extract the emotional meaning from both the faces (prime) and Chinese characters (target) and connect the emotional meanings of the two. Because a congruency effect was found here, we have more confidence that the priming effect that we obtained can be attributed to the semantic level.

The extent to which unconscious visual information can be processed under interocular suppression has been intensely debated (see Faivre et al., 2014; Lin & He, 2009; Sterzer et al., 2014; Yang et al., 2014, for reviews). Whereas some studies have revealed that invisible stimuli can elicit categorical priming (Almeida et al., 2010; Almeida, Mahon, Nakayama, & Caramazza, 2008), numerical priming (Bahrami et al., 2010), and identity priming (Barbot & Kouider, 2012), other follow-up studies were unable to replicate the results with different experimental designs and statistical analyses (Hesselmann et al., 2016; Hesselmann, Darcy, Sterzer, & Knops, 2015; Izatt, Dubois, Faivre, & Koch, 2014; Sakuraba, Sakai, Yamanaka, Yokosawa, & Hirayama, 2012). Also, comparisons between CFS and other paradigms that render stimuli invisible have shown that the “unconscious” processing under CFS seems weaker than such processing probed under other paradigms (Almeida et al., 2010; Faivre et al., 2012; Izatt et al., 2014; Peremen & Lamy, 2014). These contradictory results suggest that unconscious processing under interocular suppression might be more limited than has previously been thought and should be examined with caution.

With this in mind, by showing a priming effect from invisible faces under CFS on target words, the present study indicates that the emotional meaning of facial expressions can be extracted under CFS and influences the emotional judgments of subsequently presented words. This affective-priming effect is less likely to be either perceptual or response priming because the face primes and word targets did not share similar perceptual properties and did not serve as prime or target interchangeably. Additionally, both short and long prime durations can induce an affective-priming effect, which may also exclude the perceptual-habituation account (Barbot & Kouider, 2012). In conclusion, our findings provide yet further evidence for unconscious processing of emotional meaning under interocular suppression.

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References

- Adams, W. J., Gray, K. L., Garner, M., & Graf, E. W. (2010). High-level face adaptation without awareness. *Psychological Science*, 21, 205–210. <https://doi.org/10.1177/0956797609359508>
- Alais, D., & Blake, R. (2005). *Binocular rivalry*. Cambridge, MA: MIT Press.
- Almeida, J., Mahon, B. Z., & Caramazza, A. (2010). The role of the dorsal visual processing stream in tool identification. *Psychological Science*, 21, 772–778. <https://doi.org/10.1177/0956797610371343>
- Almeida, J., Mahon, B. Z., Nakayama, K., & Caramazza, A. (2008). Unconscious processing dissociates along categorical lines. *Proceedings of the National Academy of Sciences*, 105, 15214–15218. <https://doi.org/10.1073/pnas.0805867105>
- Almeida, J., Mahon, B. Z., Zapater-Rabero, V., Dziuba, A., Cabaco, T., Marques, J. F., & Caramazza, A. (2014). Grasping with the eyes: The role of elongation in visual recognition of manipulable objects. *Cognitive, Affective, & Behavioral Neuroscience*, 14, 319–335. <https://doi.org/10.3758/s13415-013-0208-0>
- Almeida, J., Pajtas, P. E., Mahon, B. Z., Nakayama, K., & Caramazza, A. (2013). Affect of the unconscious: Visually suppressed angry faces modulate our decisions. *Cognitive, Affective, & Behavioral Neuroscience*, 13, 94–101. <https://doi.org/10.3758/s13415-012-0133-7>
- Anderson, E., Siegel, E., White, D., & Barrett, L. F. (2012). Out of sight but not out of mind: Unseen affective faces influence evaluations and social impressions. *Emotion*, 12, 1210–1221. <https://doi.org/10.1037/a0027514>
- Bahrami, B., Vetter, P., Spolaore, E., Pagano, S., Butterworth, B., & Rees, G. (2010). Unconscious numerical priming despite interocular suppression. *Psychological Science*, 21, 224–233.
- Barbot, A., & Kouider, S. (2012). Longer is not better: Nonconscious overstimulation reverses priming influences under interocular suppression. *Attention, Perception, & Psychophysics*, 74, 174–184. <https://doi.org/10.3758/s13414-011-0226-3>
- Bates, D., Maechler, M., Bolker, B., & Walker, S. (2015). Fitting linear mixed-effects models using lme4. *Journal of Statistical Software*, 67, 1–48.
- Blake, R. (1988). Dichoptic reading: The role of meaning in binocular rivalry. *Perception & Psychophysics*, 44, 133–141.
- Blake, R., & Fox, R. (1974). Adaptation to invisible gratings and the site of binocular rivalry suppression. *Nature*, 249, 488–490.
- Blake, R., & Logothetis, N. K. (2002). Visual competition. *Nature Reviews Neuroscience*, 3, 13–21.
- Brainard, D. H. (1997). The psychophysics toolbox. *Spatial Vision*, 10, 433–436. <https://doi.org/10.1163/156856897X00357>
- Ekman, P., & Friesen, W. V. (1976). *Pictures of facial affect*. Palo Alto, CA: Consulting Psychologist Press.
- Faivre, N., Berthet, V., & Kouider, S. (2012). Nonconscious influences from emotional faces: A comparison of visual crowding, masking, and continuous flash suppression. *Frontiers in Psychology*, 3, 129. <https://doi.org/10.3389/fpsyg.2012.00129>
- Faivre, N., Berthet, V., & Kouider, S. (2014). Sustained invisibility through crowding and continuous flash suppression: A comparative review. *Frontiers in Psychology*, 5, 475. <https://doi.org/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, 175–191. <https://doi.org/10.3758/BF03193146>
- Gayet, S., Paffen, C. L., Belopolsky, A. V., Theeuwes, J., & Van der Stigchel, S. (2016). Visual input signaling threat gains preferential access to awareness in a breaking continuous flash suppression paradigm. *Cognition*, 149, 77–83. <https://doi.org/10.1016/j.cognition.2016.01.009>
- Gayet, S., Van der Stigchel, S., & Paffen, C. L. (2014). Breaking continuous flash suppression: Competing for consciousness on the pre-semantic battlefield. *Frontiers in Psychology*, 5, 460. <https://doi.org/10.3389/fpsyg.2014.00460>
- Gray, K. L., Adams, W. J., Hedger, N., Newton, K. E., & Garner, M. (2013). Faces and awareness: Low-level, not emotional factors determine perceptual dominance. *Emotion*, 13, 537–544. <https://doi.org/10.1037/a0031403>
- Hedger, N., Adams, W. J., & Garner, M. (2015). Fearful faces have a sensory advantage in the competition for awareness. *Journal of Experimental Psychology: Human Perception and Performance*, 41, 1748–1757. <https://doi.org/10.1037/xhp0000127>
- Hesselmann, G. (2013). Dissecting visual awareness with fMRI. *Neuroscientist*, 19, 495–508. <https://doi.org/10.1177/1073858413485988>
- Hesselmann, G., Darcy, N., Ludwig, K., & Sterzer, P. (2016). Priming in a shape task but not in a category task under continuous flash suppression. *Journal of Vision*, 16(3), 17. <https://doi.org/10.1167/16.3.17>
- Hesselmann, G., Darcy, N., Sterzer, P., & Knops, A. (2015). Exploring the boundary conditions of unconscious numerical priming effects with continuous flash suppression. *Consciousness and Cognition*, 31, 60–72. <https://doi.org/10.1016/j.concog.2014.10.009>
- Izatt, G., Dubois, J., Faivre, N., & Koch, C. (2014). A direct comparison of unconscious face processing under masking and interocular suppression. *Frontiers in Psychology*, 5, 659. <https://doi.org/10.3389/fpsyg.2014.00659>
- Jiang, Y., & He, S. (2006). Cortical responses to invisible faces: Dissociating subsystems for facial-information processing. *Current Biology*, 16, 2023–2029.
- Kiefer, M., Sim, E. J., & Wentura, D. (2015). Boundary conditions for the influence of unfamiliar non-target primes in unconscious evaluative priming: The moderating role of attentional task sets. *Consciousness and Cognition*, 35, 342–356. <https://doi.org/10.1016/j.concog.2015.01.010>
- Klauer, K. C., & Musch, J. (2003). Affective priming: Findings and theories. In J. Musch & K. C. Klauer (Eds.), *The psychology of evaluation: Affective processes in cognition and emotion* (pp. 7–50). Mahwah, NJ: Erlbaum.
- Lin, Z., & He, S. (2009). Seeing the invisible: The scope and limits of unconscious processing in binocular rivalry. *Progress in Neurobiology*, 87, 195–211. <https://doi.org/10.1016/j.pneurobio.2008.09.002>
- Moors, P., Hesselmann, G., Wagemans, J., & van Ee, R. (2017). Continuous flash suppression: Stimulus fractionation rather than integration. *Trends in Cognitive Sciences*, 21, 719–721. <https://doi.org/10.1016/j.tics.2017.06.005>
- Mudrik, L., Breska, A., Lamy, D., & Deouell, L. Y. (2011). Integration without awareness: Expanding the limits of unconscious processing. *Psychological Science*, 22, 764–770. <https://doi.org/10.1177/0956797611408736>
- Mudrik, L., Faivre, N., & Koch, C. (2014). Information integration without awareness. *Trends in Cognitive Sciences*, 18, 488–496. <https://doi.org/10.1016/j.tics.2014.04.009>
- Ortells, J. J., Fox, E., Noguera, C., & Abad, M. J. (2003). Repetition priming effects from attended vs. ignored single words in a semantic categorization task. *Acta Psychologica*, 114, 185–210.
- Peremen, Z., & Lamy, D. (2014). Comparing unconscious processing during continuous flash suppression and meta-contrast masking just under the limen of consciousness. *Frontiers in Psychology*, 5, 969. <https://doi.org/10.3389/fpsyg.2014.00969>
- Rabovsky, M., Stein, T., & Abdel Rahman, R. (2016). Access to awareness for faces during continuous flash suppression is not modulated by affective knowledge. *PLoS ONE*, 11, e0150931. <https://doi.org/10.1371/journal.pone.0150931>

- Rothkirch, M., & Hesselmann, G. (2017). What we talk about when we talk about unconscious processing – A plea for best practices. *Frontiers in Psychology*, 8, 835. <https://doi.org/10.3389/fpsyg.2017.00835>
- Sakuraba, S., Sakai, S., Yamanaka, M., Yokosawa, K., & Hirayama, K. (2012). Does the human dorsal stream really process a category for tools? *Journal of Neuroscience*, 32, 3949–3953. <https://doi.org/10.1523/JNEUROSCI.3973-11.2012>
- Schmack, K., Burk, J., Haynes, J. D., & Sterzer, P. (2016). Predicting subjective affective salience from cortical responses to invisible object stimuli. *Cerebral Cortex*, 26, 3453–3460. <https://doi.org/10.1093/cercor/bhv174>
- Schmidt, F., Haberkamp, A., & Schmidt, T. (2011). Dos and don'ts in response priming research. *Advances in Cognitive Psychology*, 7, 120–131. <https://doi.org/10.2478/v10053-008-0092-2>
- Sengpiel, F., Blakemore, C., & Harrad, R. (1995). Interocular suppression in the primary visual cortex: A possible neural basis of binocular rivalry. *Vision Research*, 35, 179–195.
- Sheinberg, D. L., & Logothetis, N. K. (1997). The role of temporal cortical areas in perceptual organization. *Proceedings of the National Academy of Sciences*, 94, 3408–3413.
- Stein, T., Grubb, C., Bertrand, M., Suh, S. M., & Verosky, S. C. (2017). No impact of affective person knowledge on visual awareness: Evidence from binocular rivalry and continuous flash suppression. *Emotion*, 17, 1199–1207. <https://doi.org/10.1037/emo0000305>
- 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. <https://doi.org/10.3389/fnhum.2011.00167>
- Stein, T., Kaiser, D., & Peelen, M. V. (2015). Interobject grouping facilitates visual awareness. *Journal of Vision*, 15(8), 10. <https://doi.org/10.1167/15.8.10>
- Stein, T., Seymour, K., Hebart, M. N., & Sterzer, P. (2014). Rapid fear detection relies on high spatial frequencies. *Psychological Science*, 25, 566–574. <https://doi.org/10.1177/0956797613512509>
- Stein, T., & Sterzer, P. (2012). Not just another face in the crowd: Detecting emotional schematic faces during continuous flash suppression. *Emotion*, 12, 988–996. <https://doi.org/10.1037/a0026944>
- Stein, T., & Sterzer, P. (2014). Unconscious processing under interocular suppression: Getting the right measure. *Frontiers in Psychology*, 5, 387. <https://doi.org/10.3389/fpsyg.2014.00387>
- Stein, T., Thoma, V., & Sterzer, P. (2015). Priming of object detection under continuous flash suppression depends on attention but not on part-whole configuration. *Journal of Vision*, 15(3), 15. <https://doi.org/10.1167/15.3.15>
- Sterzer, P., Hilgenfeldt, T., Freudenberg, P., Bermpohl, F., & Adli, M. (2011). Access of emotional information to visual awareness in patients with major depressive disorder. *Psychology and Medicine*, 41, 1615–1624. <https://doi.org/10.1017/S0033291710002540>
- Sterzer, P., Stein, T., Ludwig, K., Rothkirch, M., & Hesselmann, G. (2014). Neural processing of visual information under interocular suppression: A critical review. *Frontiers in Psychology*, 5, 453. <https://doi.org/10.3389/fpsyg.2014.00453>
- Tong, F., Nakayama, K., Vaughan, J. T., & Kanwisher, N. (1998). Binocular rivalry and visual awareness in human extrastriate cortex. *Neuron*, 21, 753–759.
- Tsuchiya, N., & Koch, C. (2005). Continuous flash suppression reduces negative afterimages. *Nature Neuroscience*, 8, 1096–1101.
- Tsuchiya, N., Moradi, F., Felsen, C., Yamazaki, M., & Adolphs, R. (2009). Intact rapid detection of fearful faces in the absence of the amygdala. *Nature Neuroscience*, 12, 1224–1225. <https://doi.org/10.1038/nn.2380>
- Wade, N. J., & Wenderoth, P. (1978). The influence of colour and contour rivalry on the magnitude of the tilt after-effect. *Vision Research*, 18, 827–835.
- Whalen, P. J., Kagan, J., Cook, R. G., Davis, F. C., Kim, H., Polis, S., ... Johnstone, T. (2004). Human amygdala responsivity to masked fearful eye whites. *Science*, 306, 2061. <https://doi.org/10.1126/science.1103617>
- Yang, E., Brascamp, J., Kang, M. S., & Blake, R. (2014). On the use of continuous flash suppression for the study of visual processing outside of awareness. *Frontiers in Psychology*, 5, 724. <https://doi.org/10.3389/fpsyg.2014.00724>
- Yang, E., Hong, S. W., & Blake, R. (2010). Adaptation aftereffects to facial expressions suppressed from visual awareness. *Journal of Vision*, 10(12), 24. <https://doi.org/10.1167/10.12.24>
- Yang, E., Zald, D. H., & Blake, R. (2007). Fearful expressions gain preferential access to awareness during continuous flash suppression. *Emotion*, 7, 882–886. <https://doi.org/10.1037/1528-3542.7.4.882>
- Zadbood, A., Lee, S. H., & Blake, R. (2011). Stimulus fractionation by interocular suppression. *Frontiers in Human Neuroscience*, 5, 135. <https://doi.org/10.3389/fnhum.2011.00135>
- Zimba, L. D., & Blake, R. (1983). Binocular rivalry and semantic processing: Out of sight, out of mind. *Journal of Experimental Psychology: Human Perception and Performance*, 9, 807–815.