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Eye gaze direction modulates nonconscious affective contextual effect

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ABSTRACT

Facial emotion recognition is inherently contextualized and may automatically incorporate affective information from the context. Here we investigate whether this affective contextual effect is modulated by a prominent social cue, namely, the gaze direction of the contextualized emotional face. We demonstrate that the perceived emotional expression of a visible target face is biased toward the emotion of an invisible contextual face, with this nonconscious affective contextual modulation dependent on the gaze direction of the target face. In particular, a target face gazing toward a contextual face induced a larger affective contextual effect than a face gazing away. Furthermore, this gaze modulation effect specifically occurred for invisible fearful contexts and hinged on individual trait anxiety levels. These findings show that social information delivered by gaze cues can modulate the fear-specific affective contextual effect without awareness, shedding new light on how compound socio-affective signals are automatically integrated into our perception of others' emotions.

1. Introduction

Deciphering emotional messages from others is invaluable in developing adaptive behaviors within a social environment. Among the most common affective cues, facial expressions are thought to provide critical diagnostic information about basic emotions (Ekman, 1992a, 1992b; Izard, 1994) and affective dimensions (Russell, 1980, 2003). Indeed, researchers have long assumed that people could 'read out' the emotional state of others merely by analyzing their facial features and configurations, and concentrated primarily on emotion recognition from isolated faces while neglecting the influence of contextual factors (Adolphs, 2002a, 2002b; Mende-Siedlecki et al., 2013).

In the recent two decades, growing attention has been paid to the context in which facial emotions are encoded (Aviezer et al., 2017; de Gelder et al., 2006; Wieser & Brosch, 2012). Different lines of evidence have converged to the point that the perception of facial emotions is not as unequivocal as it might seem to be without referring to a meaningful context (Fernandez-Dols & Crivelli, 2013; Parkinson, 2013). In particular, a broad range of affective contexts, including verbal descriptions, body actions, visual scenes, and other people's faces, all appear to modulate how people perceive emotion from a facial expression (Barrett et al., 2011; Wieser &

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Brosch, 2012). Besides, the presence of an affective context can bias or largely determine the perceived emotion of an ambiguous or morphed facial expression (Aviezer et al., 2011; Gray et al., 2017; Lee et al., 2012). More impressively, observers are able to infer the affective valence and arousal levels of unseen target characters based solely on highly realistic contextual information extracted from movie clips (Chen & Whitney, 2019). Altogether, these findings provide strong evidence that facial emotion perception is inherently contextualized and the affective contexts may serve as a modulating or even determinant factor for emotion recognition in real-life situations (Aviezer et al., 2017; Chen & Whitney, 2019; Hassin et al., 2013).

Remarkably, the integration of the affective context and the emotional face seems to be an early and automatic process. Emotional congruency between the faces and contexts can modulate the amplitude of early ERP components, such as P1 or N170 (Meeren et al., 2005; Righart & De Gelder, 2006, 2008). More intriguingly, the affective contextual effect remains to occur when participants are required to ignore the visual contexts or perform the facial expression classification task with a high cognitive load (Aviezer et al., 2011). Furthermore, contextual emotional faces that are subliminally presented or rendered invisible may still influence facial expression discrimination of the target faces (Mumenthaler & Sander, 2015; Ye et al., 2014). These findings support the notion that the affective contextual modulation proceeds in an automatic rather than a controlled manner (Aviezer et al., 2011; de Gelder et al., 2006; Wieser & Brosch, 2012).

Besides emotions, faces also carry other prominent social cues, such as eye gaze. Eye gaze direction provides a window into a person's intention (Emery, 2000) and can enrich the meanings of facial expressions to affect emotion perception (Adams & Kleck, 2003; Sander et al., 2007). However, the role of gaze cues in the affective contextual effect remains largely unexplored. When facing a compound scene that an emotional face gazes toward an emotionally charged context, observers tend to integrate the facial expression,

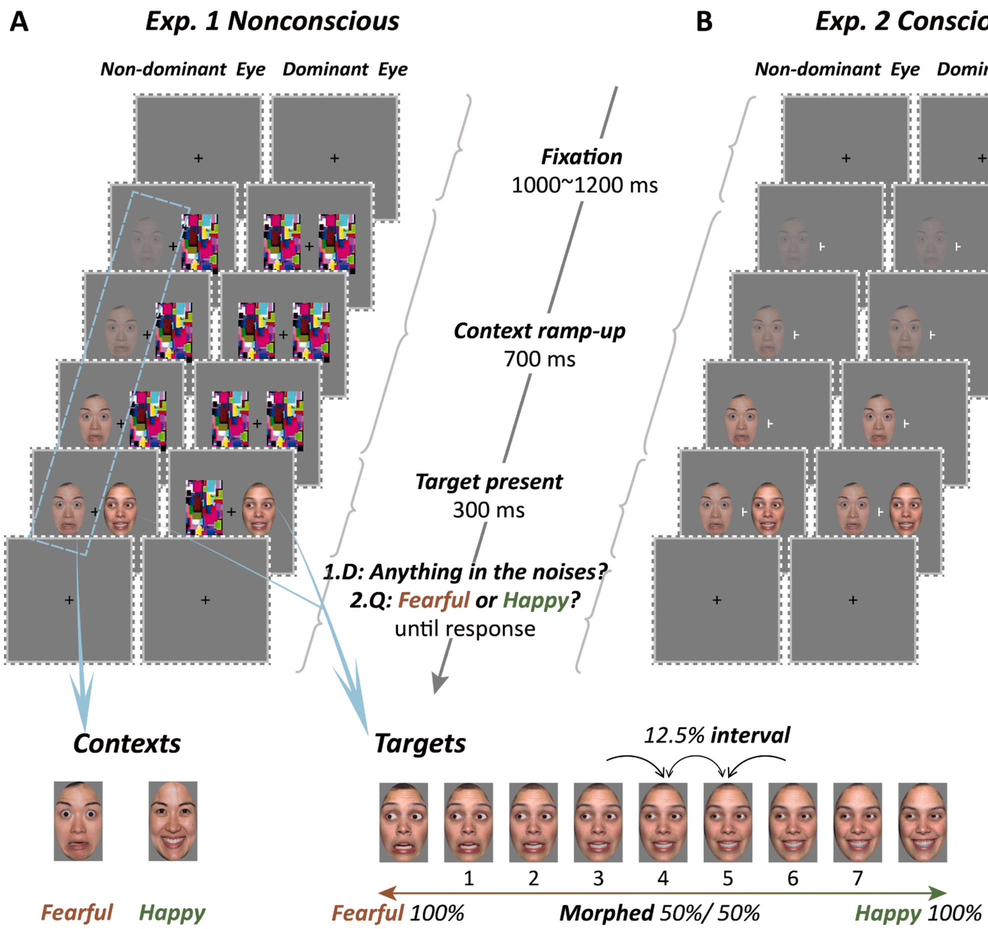

Fig. 1. Illustrations of example trials and sample stimuli in the nonconscious (Exp. 1) and the conscious (Exp. 2) experiments. (A) In Exp. 1, the contextual face presented to the non-dominant eye, at one side of fixation, was masked by the full-contrast dynamic noises in the dominant eye. The contrast of the contextual face ramped up from 0 to 0.5 over 700 ms and remained at 0.5 in the next 300 ms. Meanwhile, on the contrary side of the contextual face in both eyes, the dynamic noises flashed at 10 Hz in the first 700 ms and then were replaced by a target emotional face presented for 300 ms. The gaze orientation of the target face was toward or away from the context side. **(B)** In Exp. 2, the same context and target were presented binocularly, and there were no dynamic noises. In both Exp. 1 and Exp. 2, the participants were asked to make a two-alternative forced-choice (2AFC) to judge whether the target face was fearful or happy. Before the judgment, we also required participants to detect whether they saw anything in the dynamic noises in Exp. 1.

the eye gaze direction of the face, and the emotional valence of the context to infer the person's state of awareness (Kelly et al., 2014). Moreover, social inferences based on combined gaze-expression cues in the context can be automatically integrated into facial emotion recognition (Mumenthaler & Sander, 2015). Apart from the gaze-emotion interaction at the behavioral level, gaze and facial emotion processing share overlapping neurocognitive mechanisms (Graham & Labar, 2012). These observations illustrate the complex entanglement of eye gaze direction and emotion processing in social cognition, indicating the possibility that the eye gaze direction of an emotional face may modulate the affective contextual effect.

Here we assessed this possibility by manipulating the gaze direction of an emotionally ambiguous target face while introducing another emotional face adjacent to it as a context (Fig. 1). We were particularly interested in whether and how automatically the gaze direction of the target face would modulate the affective contextual effect. To this end, we rendered the contextual face invisible using continuous flash suppression (CFS) (Tsuchiya & Koch, 2005) and examined whether an affective contextual effect could arise in a way sensitive to the direction of the target gaze cue even in the absence of visual awareness. We used the emotional faces as contexts, as they can be processed without conscious awareness (Axelrod et al., 2015; Tamietto & De Gelder, 2010), opening the possibility to explore the nonconscious contextual effect. In addition, one person gazing at or away from another person does convey distinct social meanings, which may result in gaze modulation of the affective contextual effect. Above all, the eye gaze cue can rapidly direct the observer's attention to the gaze direction (Friesen & Kingstone, 1998; Ji et al., 2020). Such reflexive attentional orienting may enhance the processing of the gaze-directed emotional context and thus facilitate automatic integration of affective cues across the target and context. Besides, gaze direction cues may influence the observer's inferences about whether the gaze sender is aware of the gazed context (Kelly et al., 2014). Therefore, relative to the gaze-away condition, target faces gazing toward contextual faces may strengthen the link between the two persons through social attribution, which further promotes integrative processing of the target and contextual emotion. For either reason, we would expect to observe a greater affective contextual effect for target faces gazing at the invisible contextual face than for faces gazing in the opposite direction.

As to nonconscious facial emotion processing, previous research has revealed a specificity for fearful facial expression. Invisible fear, as a threat-related expression, can attract more attention than other non-threat-related facial expressions (Carlson & Reinke, 2008; Fox, 2002). The superior sensitivity to nonconscious fear may be supported by a rapid, subcortical pathway routed through the superior colliculus and the pulvinar to the amygdala (McFadyen et al., 2020; Tamietto & De Gelder, 2010). Also, the processing of threat-related emotions (e.g., fear) is closely associated with personality traits (Calder et al., 2011; Lee et al., 2012; Wieser & Brosch, 2012). Particularly, individuals with high trait anxiety are more sensitive to threat-related expressions even without awareness (Bar-Haim et al., 2007; Mogg & Bradley, 1999). Based on these findings, we hypothesized that gaze direction could modulate the affective contextual effect even when the context was not consciously perceived, and such modulation effect might be more evident under the fearful context and more likely to appear in individuals with high trait anxiety.

2. Material and methods

2.1. Participants

A total of 88 participants (mean age $\pm$ SD $= 22.01 \pm 2.18$ years, 52 females), with normal or corrected-to-normal vision, took part in this study. 44 of them participated in Experiment 1 (21.91 ± 2.23 years, 25 females), and the rest in Experiment 2 (22.11 ± 2.15 years, 27 females). The State-Trait Anxiety Inventory-Trait version (STAI-T) (Spielberger et al., 1983) was administered to all participants before the experiments. In each experiment, 22 participants who scored with 42 (median score of this sample) or over were allocated into the High Trait Anxiety (HTA) group, another 22 individuals who scored less than 42 were assigned to the Low Trait Anxiety (LTA) group. All participants were naive to the purpose of this study. They had given informed consent approved by the institutional review board of the Institute of Psychology, Chinese Academy of Sciences before the experiment and received monetary rewards after their participation.

We determined the sample size based on G*Power, version 3.1.9.4 (Faul et al., 2007). A sample size of 38 participants would be sufficient (power $= 0.80$, $\alpha = 0.05$) to detect a moderate to large affective contextual effect ($\eta_p^2 = 0.10$) in the conscious social interaction scene, according to a study using a similar design and paradigm to our own (Gray et al., 2017). We also estimated that to detect a large effect size with $\eta_p^2 > 0.14$ for the interactive influence of trait anxiety on different invisible emotional facial expressions processing, 10 participants per trait anxiety group were required to afford 80% power at 0.05 α-level (Fox, 2002). We further increased the sample size to 44 per experiment (22 per trait anxiety group in each experiment) to adequately detect the affective contextual modulation in the current study.

2.2. Stimuli and apparatus

Raw facial stimuli were chosen from the NimStim Face Stimulus Set (Tottenham et al., 2009). We used PhotoShop software to manipulate these raw images, including removing the hair and other non-facial features outside the face, and matching colors for the remaining central oval facial area. From these pre-processed images, we selected 16 faces with either a fearful or happy expression (8 distinct identities, half males) as contextual face stimuli (Fig. 1, Contexts), and another 8 fearful or happy faces (4 distinct identities, half males) to generate the target stimuli. For target face generation, we first manipulated the gaze direction of each face, either to the left or to the right. Then, we employed the 100% fearful and the 100% happy faces with the same identity and the same gaze orientation to create a sequence of emotionally "morphed" faces (Abrosoft FantaMorph software, version 5.0). For each combination of face identity and gaze orientation, the middle 7 "morphed" faces (labeled number 1–7), linearly spanning from 12.5% fearful + 87.5%

happy to 87.5% fearful + 12.5% happy with a step of 12.5% change of facial expression, were set as the targets (Fig. 1, Targets).

Visual stimuli were displayed against a gray background on a 19-inch CRT monitor (refresh rate: 60 Hz, spatial resolution: 1,280 × 1,024 pixels) using MATLAB (The MathWorks, Natick, MA) along with the Psychophysics Toolbox extensions (Brainard, 1997). All stimuli appeared within two rectangular frames (9.97°×9.97°) displayed at the centers of the left half and right half of the screen to help participants achieve a stable fusion of the dichoptic stimuli. Participants viewed the screens through a pair of stereoscopes, which projected the stimuli separately into their left and right eyes. They were required to place their heads on a chin rest to maintain a fixed viewing distance of 60 cm.

2.3. Procedure

In Experiment 1 (Fig. 1**A**), each trial started with a black fixation cross (0.45°×0.45°) displayed at the center of the fusion frame for each eye. The central cross would be ever-present during each trial, and participants were required to maintain fixation on it throughout the trial. After 1000 ~ 1200 ms, the visual stimuli were displayed dichoptically to the two eyes. In the non-dominant eye, a contextual face (1.45°×2.40°) alongside with dynamic Mondrian noises (1.60°×2.64°) varying randomly at a rate of 10 Hz was displayed on the left and right sides of the fixation cross, respectively. The contrast of the contextual face ramped up linearly from 0 to 50% across a period of 700 ms and kept constant during the next 300 ms, whereas on the other side of the cross fixation, the noises flashed at 10 Hz during the first 700 ms and were replaced by a target face during the subsequent 300 ms. In the dominant eye, two dynamic noises were presented side by side for the first 700 ms, then in the last 300 ms, one of the noises was replaced by the target face appearing at the corresponding location of the non-dominant eye. In this CFS task, the noises in the dominant eye suppressed the perception of stimuli in the non-dominant eye, thus rendering the contextual face invisible. Thus, participants perceptually saw two dynamic noises side by side at first and then perceived one of the noises turning into an emotional face that gazed toward or away from the dynamic noises on the other side. After the stimuli disappeared, only the fixation cross remained on the screen until the participants completed a two-alternative forced-choice (2AFC) task. They indicated the perceived emotion (fearful or happy) of the target face by pressing one of two keys (left-arrow and right-arrow). The assignments of keys corresponding to fearful and happy responses were counterbalanced across participants. To eschew the possibility that contextual faces broke through suppression during the trial, participants were also instructed to press the up-arrow key before doing the 2AFC task if they detected anything in the noise other than the simple dynamic Mondrian patterns. In addition to the ordinary (non-conscious) trials, we added catch trials in which the suppressed contextual faces were blended into the dynamic noise patterns with a contrast of 0.6, and the visual representations of the catch trials were the same as the trials that went beyond nonconsciousness. Participants were expected to press the up-arrow key in these catch trials. Each participant completed a total of 560 ordinary trials run in random order, with four treatment conditions (2 context expressions: fearful, happy × 2 target gaze orientations: toward, away) at 7 stimuli morphed levels repeated 20 times, respectively. Every 20 ordinary trials were interspersed with 1 or 2 catch trials, resulting in a total of 30 catch trials.

Experiment 2 followed the same procedure as Experiment 1, with three exceptions in the stimulus presentation stage (Fig. 1**B**). Firstly, there were no dynamic noises to suppress the contextual face, and participants received the same images to their two eyes. Therefore, they could consciously perceive both the target face and the contextual face. Secondly, to indicate on which side of the visual field the target images appeared, in each trial, we replaced the black fixation cross with a white T-shaped pointer (rotate ± 90°), whose horizontal line pointed to the target face. Beyond that, this experiment had no catch trials, and participants did not need to implement the awareness check task.

2.4. Data analysis

For each participant under each treatment condition, the proportions of happy responses were calculated for seven morph levels of the target (from fearful to happy), respectively. Then the data were fit to psychometric function ('logistic', $S(x;m,w) = \frac{1}{1+e^{-2\log(\frac{1}{.05}-1)\frac{x-m}{w}}}$) using the *psignifit* toolbox version 4.0 for MATLAB (Wichmann & Hill, 2001) to obtain the point of subjective equality (PSE) and the different limen (DL) of the psychophysical curves. The PSE represents the point at which participants equally perceived the target emotion as happy and fearful. The larger the PSE, the more fearful the participant perceived the target to be. Additionally, DL (half the interquartile range of the fitted function) was the index to show participants' sensitivity to discriminate target emotions. The smaller the DL value, the higher the sensitivity.

To normalize the modulation effect of gaze direction in different emotional context conditions and across participants, we calculated a gaze modulation index (GMI) for PSE and DL, respectively, as follows:GMI $= \frac{G_{toawrd} - G_{away}}{G_{toawrd} + G_{away}}$. G_{toward} is the PSE (or DL) for target faces that gazed toward the context, and G_{away} serves as a baseline where the target gazed away from the context. For $PSE_{GMI,}$ values significantly higher than 0 mean that the facial emotion of the target is perceived as more fearful in the more socially relevant condition, and values lower than 0 indicate the reverse. For DL_{GMI}, the smaller the value, the more sensitive the participant is in discriminating the target facial emotion in a social interaction scene.

3. Results

3.1. Experiment 1: Nonconscious context

In the nonconscious experiment, all participants missed no more than 3.106% of the catch trials. Data from trials in which suppression was incomplete were excluded from the analysis, leading to 98.46% of valid trials on average. Crucially, the three-way interaction on PSEs among context expression, target gaze orientation, and trait anxiety was significant ($F(1,42) = 8.626$, $p = .005$, $\eta_p^2 = 0.170$), with a main effect of gaze orientation ($F(1,42) = 4.459$, $p = .041$, $\eta_p^2 = 0.096$), but not context expression ($F(1,42) = 3.144$, $p = .083$, $\eta_p^2 = 0.070$) and trait anxiety ($F(1,42) = 0.207$, $p = .651$, $\eta_p^2 = 0.005$). Further analysis on the gaze modulation effect showed that, in the fearful context condition, target faces gazing toward the invisible contextual faces were perceived as more fearful relative to those gazing away for HTA individuals (Fig. 2**A**) ($t(21) = 3.487$, $p = .002$, Cohen's $d = 0.743$, 95% CI [1.249, 4.942], $BF_{10} = 18.042$); however, such modulation effect was absent for LTA individuals (Fig. 2**B**) ($t(21) = 0.091$, $p = .928$, Cohen's $d = 0.019$, 95% CI [−2.342, 2.557], $BF_{10} = 0.224$). By contrast, in the happy context condition, gaze directions did not modulate emotion judgment in HTA group (Fig. 2**C**) ($t(21) = 0.053$, $p = .958$, Cohen's $d = 0.011$, 95% CI [−2.087, 2.196], $BF_{10} = 0.223$) and induced a marginal difference of the perceived emotion in LTA group (Fig. 2**D**) ($t(21) = 1.830$, $p = .081$, Cohen's $d = 0.390$, 95% CI [−0.254, 3.976], $BF_{10} = 0.921$).

To facilitate comparisons across participants and conditions, we then obtained a gaze modulation index (PSE_{GMI}) for each individual and each emotional context condition (Fig. 3**A**; see the "Data Analysis" section for details). Consistent with the non-normalized results, for the HTA group, the gaze modulation effect (PSE_{GMI} value different from 0) was only observed in the fearful context condition ($t(21) = 3.332$, $p = .003$, Cohen's $d = 0.710$, 95% CI [0.010, 0.044], $BF_{10} = 13.205$) but not in the happy condition ($t(21) = 0.083$, $p = .935$, Cohen's $d = 0.018$, 95% CI [−0.019, 0.021], $BF_{10} = 0.224$). By contrast, the results of the LTA group showed a different pattern. The PSE_{GMI} value was not significantly different from 0 when the expressions of the invisible contextual faces were fearful ($t(21) = -0.009$, $p = .993$, Cohen's $d = 0.002$, 95% CI [−0.023, 0.023], $BF_{10} = 0.223$), but was slightly above 0 for the happy context ($t(21) = 1.834$, $p = .086$, Cohen's $d = 0.385$, 95% CI [−0.003, 0.037], $BF_{10} = 0.888$). These results clearly suggest that the affective context effect is modulated by the gaze cues in a way dependent on the emotion of the invisible contextual faces and the participants'

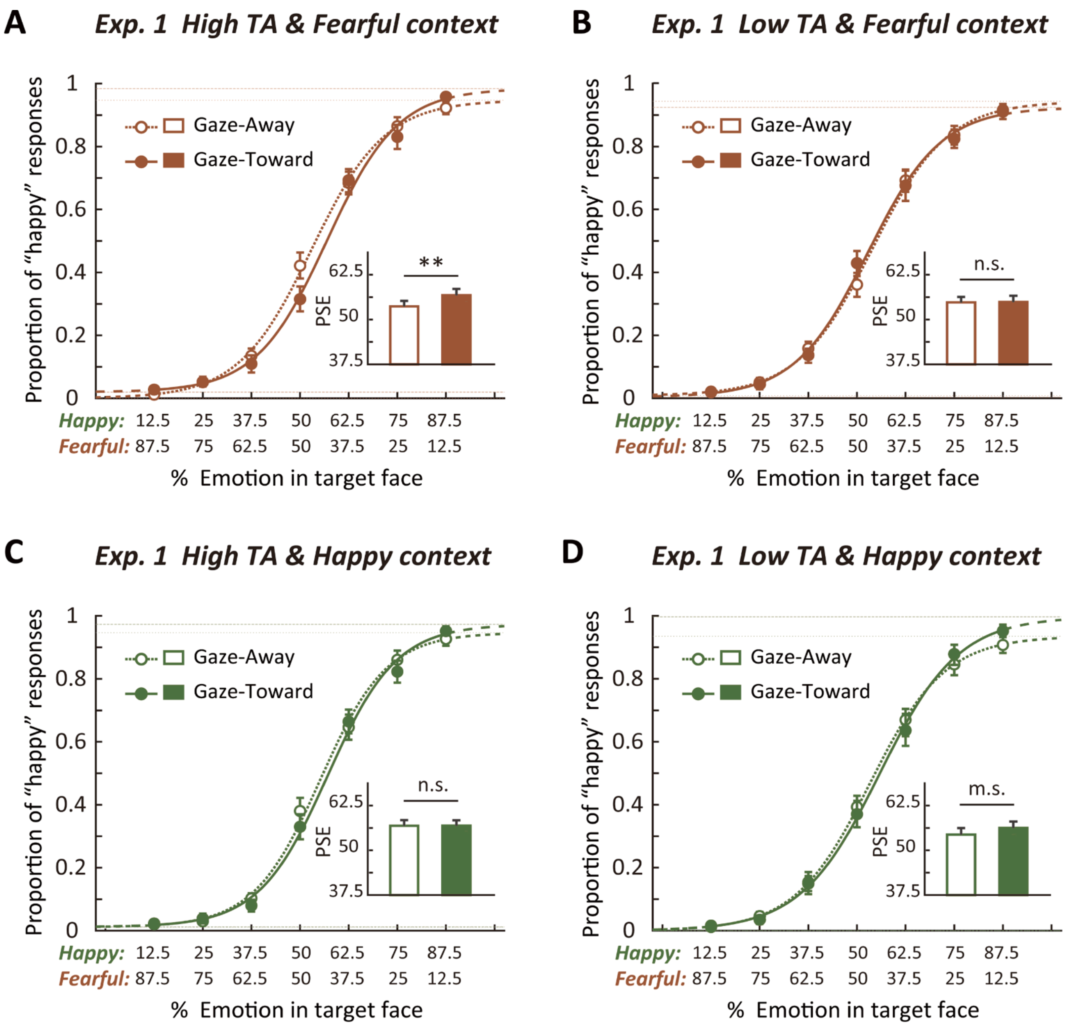

Fig. 2. Psychometric curves and the group PSE results for Exp. 1. Emotion judgment biases are reflected by the shift of PSEs induced by nonconscious fearful (**A, B**) or happy (**C, D**) contexts in individuals with high or low trait anxiety (TA) levels. Error bars show standard errors of mean. $^{**}p < .01$, m.s.: marginally significant, n.s.: nonsignificant.

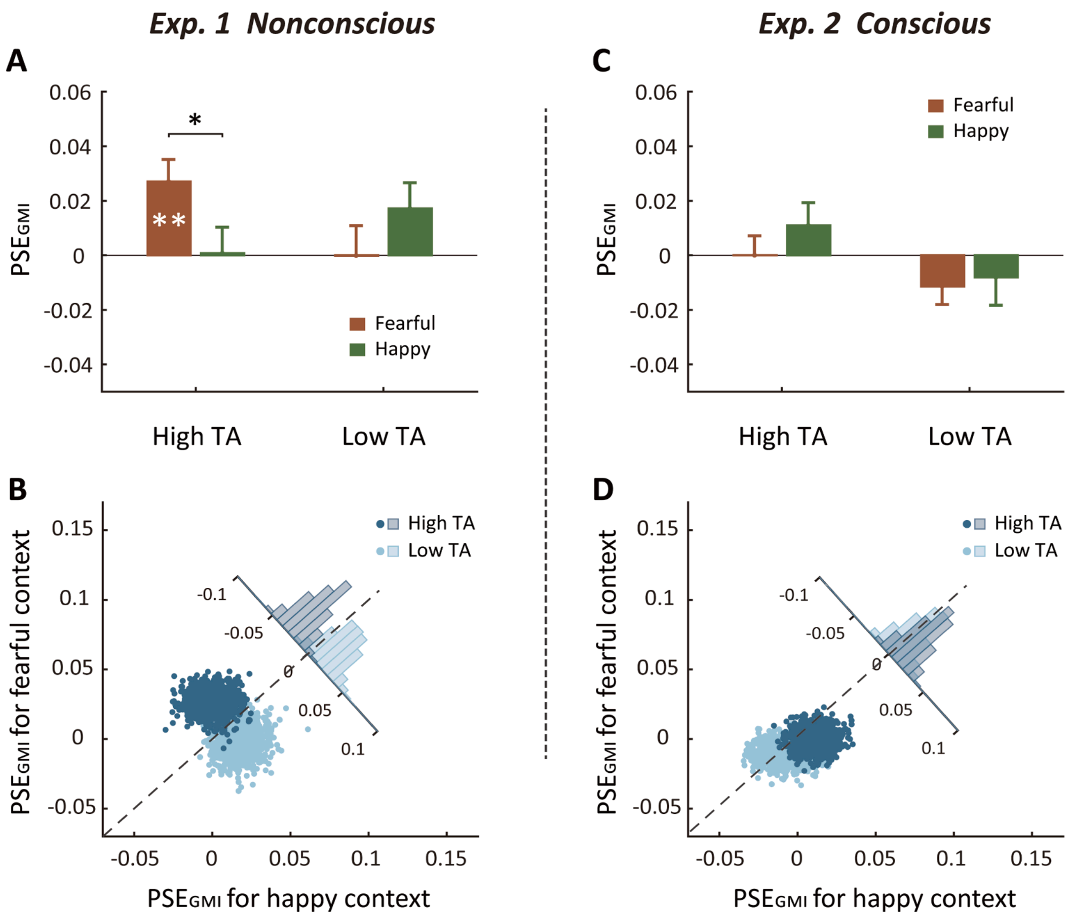

Fig. 3. Results of gaze modulation index (GMI) of PSE for the nonconscious (Exp. 1) and the conscious (Exp. 2) experiments. (A & C) PSE_{GMI} for the fearful and happy context conditions in observers with high or low trait anxiety (TA) levels. **(B & D)** Bivariate distributions of 1000 bootstrapped sample means. Error bars show standard errors of mean. *$p < .05$, **$p < .01$.

anxiety traits.

A two-way repeated-measures ANOVA verified that there was a significant interaction between the expressions of the contextual faces and trait anxiety levels of the participants ($F(1,42) = 8.895$, $p = .005$, $\eta_p^2 = 0.175$) (Fig. 3**A**). In particular, there was a significant difference between the fearful and happy context conditions, specifically for the HTA group ($t(21) = 2.706$, $p = .013$, Cohen's $d = 0.577$, 95% CI [0.006, 0.046], $BF_{10} = 3.939$), but not for the LTA group ($t(21) = -1.583$, $p = .128$, Cohen's $d = 0.338$, 95% CI [−0.040, 0.005], $BF_{10} = 0.657$). In other words, only for the HTA group, there was a substantial dissociation of gaze modulation on the emotional contextual effects between the fearful and happy context conditions. To further illustrate the difference between the HTA group and the LTA group, we plotted the bivariate distributions of PSEs with 1000 bootstrap samples for the two contextual conditions (Fig. 3**B**). The participants with HTA but not LTA mostly fell above the dashed line of slope 1, showing the dissociation of invisible contexts with different expressions between individual trait anxiety levels. Meanwhile, the same analysis conducted on DL_{GMI} yielded no significant interaction between context expression and trait anxiety ($F(1,42) = 0.245$, $p = .623$, $\eta_p^2 = 0.006$), suggesting that the observed interaction in PSE_{GMI} is not likely to be caused by differences in participants' discrimination sensitivities.

3.2. Experiment 2: Conscious context

In Experiment 1, we observed an affective contextual effect that was modulated by gaze directions, and this effect was specific to HTA individuals in threat-related contexts. As high anxious individuals tend to deal with nonconscious threat-related information automatically in the early stage of processing (Bar-Haim et al., 2007; Mogg & Bradley, 1999), it would be intriguing to investigate whether the effect found in Experiment 1 would still occur if the participants were aware of the affective context. To test this issue, we conducted Experiment 2 with a similar design as Experiment 1, except that both the target and contextual faces were visible to the participants.

Three-way repeated measures ANOVA on PSEs revealed no significant interaction among context expression, target gaze orientation, and trait anxiety ($F(1,42) = 0.257$, $p = .615$, $\eta_p^2 = 0.006$), and no significant main effect of target gaze orientation (Away vs.

Toward: 56.28vs. 56.01, Main effect: $F(1,42) = 0.317$, $p = .576$, $\eta_p^2 = 0.007$) and trait anxiety (HTA vs. LTA: 55.78 vs. 56.51, Main effect: $F(1,42) = 0.096$, $p = .759$, $\eta_p^2 = 0.002$), but a significant main effect of context expression (Fearful vs. Happy context: 56.96 vs. 55.34, $F(1,42) = 9.207$, $p = .004$, $\eta_p^2 = 0.180$). When directly looking into the gaze modulation effect, the PSEs differences between gaze-toward and gaze-away condition were not significant for either contextual facial emotions in the HTA group (Fearful context: 56.34 vs. 56.44; Happy context: 55.77 vs. 54.58; $ps > 0.1$) or the LTA group (Fearful context: 56.89 vs. 58.15; Happy context: 55.08 vs. 55.95; $ps > 0.1$).

The gaze modulation effect (PSE_{GMI}) was not significant in any trait anxiety and context conditions (Fig. 3C; $ps > 0.1$). Moreover, a two-way repeated-measures ANOVA on the PSE_{GMI} revealed that neither the interaction ($F(1,42) = 0.215$, $p = .645$, $\eta_p^2 = 0.005$) between trait anxiety levels and context expressions nor the main effects of these two variables reached significance (trait anxiety: $F(1,42) = 3.389$, $p = .073$, $\eta_p^2 = 0.075$, context expression: $F(1,42) = 0.759$, $p = .389$, $\eta_p^2 = 0.018$ (Fig. 3**C**). These patterns were also supported by the bootstrap distributions of PSEs for the HTA and LTA groups, which both fell on the line of slope 1 (Fig. 3**D**). As for DL_{GMI}, there was no significant interaction between these factors ($F(1,42) = 0.022$, $p = .882$, $\eta_p^2 = 0.001$), and neither of the main effects of trait anxiety and context expression was significant (trait anxiety: $F(1,42) = 0.586$, $p = .448$, $\eta_p^2 = 0.014$, context expression: $F(1,42) = 2.791$, $p = .102$, $\eta_p^2 = 0.062$). Together, these results clearly suggest that the gaze modulation effect found in Experiment 1 is exclusive to the nonconscious state.

3.3. Comparisons of the nonconscious and the conscious experiments

To further investigate the role of awareness in the gaze-mediated emotional contextual effect, we included consciousness states (nonconscious, conscious) and anxiety groups (HTA, LTA) in the analysis as between-subject factors, using the difference of PSE_{GMI} between fearful and happy context conditions (ΔPSE_{GMI}) as the dependent variable. A two-way repeated-measures ANOVA showed a significant interaction ($F(1,84) = 5.441$, $p = .022$, $\eta_p^2 = 0.061$) between consciousness states and trait anxiety groups (Fig. 4**A**). Follow-up analysis yielded a significant contrast between the conscious and nonconscious conditions for the HTA individuals ($t(42) = 2.781$, $p = .008$, Cohen's $d = 0.839$, 95% CI [0.010, 0.064], $BF_{10} = 5.803$) and a remarkable difference between the HTA and LTA group in the nonconscious context condition ($t(42) = 2.983$, $p = .005$, Cohen's $d = 0.899$, 95% CI [0.014, 0.073], $BF_{10} = 8.818$). More importantly, we found a positive correlation of trait anxiety scores and ΔPSE_{GMI}, only for the nonconscious context condition ($r(44) = 0.439$, $p = .003$, $BF_{10} = 13.770$) (Fig. 4**B**), but not for the conscious context condition ($r(44) = -0.119$, $p = .443$, $BF_{10} = 0.250$) (Fig. 4**C**). These findings further verify the dissociation between the nonconscious and the conscious gaze modulation effects, suggesting that the former but not the later effect is associated with the participants' trait anxiety level.

4. Discussion

Previous studies have noted the importance and necessity of affective contexts in the interpretation of facial expressions and underlined the quick or automatic integration of the contextual information and facial emotion (Aviezer et al., 2011; Aviezer et al., 2017; Chen & Whitney, 2019, 2021; Mumenthaler & Sander, 2015; Righart & De Gelder, 2006, 2008; Ye et al., 2014). The current study extended these findings by revealing how the gaze direction of the emotion expresser modulates the affective contextual effect. We found that the perceived emotion of a visible target face was biased toward the expression of a concurrently presented invisible contextual face, when the target face gazed toward compared with away from the context. More intriguingly, this gaze modulation effect occurred only when the contextual faces were rendered invisible.

Essentially, the occurrence of the affective contextual effect entails involuntary integration of the emotional face and the affective contexts (Aviezer et al., 2011; Aviezer et al., 2017; Chen & Whitney, 2019, 2021; Righart & De Gelder, 2006, 2008; Ye et al., 2014). On top of that, the gaze modulation of the affective contextual effect may involve more complex integrative processing of the emotional information and the social signals delivered by gaze cues (Kelly et al., 2014; Mumenthaler & Sander, 2015). In the current study, it is possible that various factors modulate the integration of socio-affective information and lead to the gaze modulation effect. First of all,

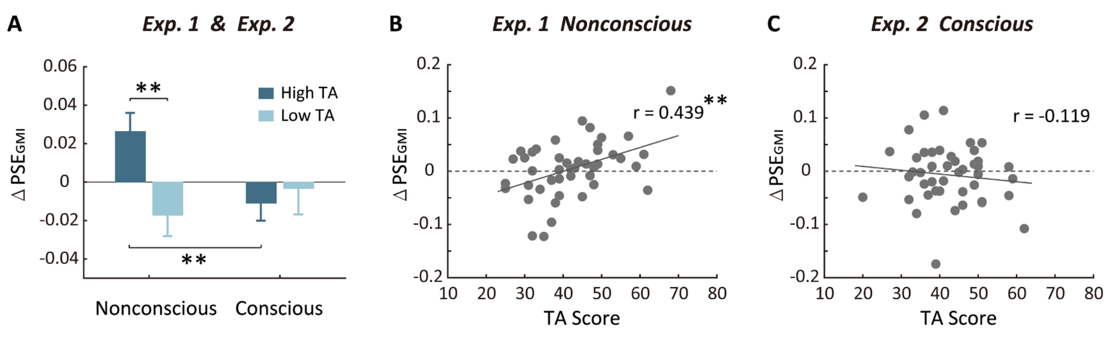

Fig. 4. Dissociations between the nonconscious and the conscious experiments. (A) ΔPSE_{GMI} for the two trait anxiety groups in the nonconscious and the conscious contextual conditions. **(B & C)** Correlations between trait anxiety (TA) scores and ΔPSE_{GMI}. Error bars show standard errors of mean. $^{**}p < .01$.

the gaze direction of other people can trigger rapid and involuntary attentional orienting of observers (Emery, 2000; Friesen & Kingstone, 1998; Frischen et al., 2007; Ji et al., 2020) and modulate further processing of the items in the gaze direction (Bayliss et al., 2006; Dodd et al., 2012; Kaisler & Leder, 2016; Landes et al., 2016; Reid & Striano, 2005). Hence, a target face gazing at the contextual face can direct the observers' attention toward it, which may facilitate emotion processing of the context and thereby promote automatic integration of the target and context. In addition, from a third-person perspective, gaze direction of a person can influence observers' social attribution about whether the person is aware of the concurrent context (Kelly et al., 2014). Therefore, a target face gazing toward a contextual face may automatically collaborate to form a meaningful, compound scene (de Gelder et al., 2006; Wieser & Brosch, 2012), with the gaze cue being a powerful adhesive in this process to facilitate the integration of socio-affective cues within this scene (Emery, 2000).

In the current study, the gaze modulation of the affective contextual effect occurred merely with the invisible context and was specific to the fearful context condition, revealing the coupled impact of context visibility and facial expression. When the contexts were invisible (Experiment 1), we found a dissociable effect in contexts of different emotions (fearful and happy). The perceived target expression was biased toward the emotion of the contexts in the fearful condition, but not when the contexts carried happy expressions. This discrepancy might be attributed to the fact that the processing of facial expressions often has divergent evolutionary implications among different emotions. For example, a fearful face often signalizes a potential threat in the environment (Wieser & Keil, 2014), forcing people to make a rapid decision to 'fight-or-flight', whereas a happy facial expression may serve as a safety signal that conveys the affiliative intent of others (Mehu & Dunbar, 2008; Mehu et al., 2007). Moreover, it is believed that there is an 'automatic' threat-sensitive mechanism to help people survive or cope with danger, even without consciousness or attention (Hedger et al., 2016). This mechanism may contribute to the fear-specific nonconscious affective contextual effect. By contrast, when the contexts were visible (Experiment 2), we did not observe the gaze modulation effect regardless of the contextual emotion. These results seem to be inconsistent with the previous finding of a happy-specific contextual effect modulated by social interaction cues (i.e., facing direction: face-to-face vs. back-to-back) (Gray et al., 2017). It is probably because our stimuli may not provide a consciously perceived social interaction cue as strong as the face-to-face cues or other more realistic interactive cues. Future studies can use a real scene (Chen & Whitney, 2019, 2021) or manipulate the relative size of the faces to maximize the authenticity of the compound scene (Mumenthaler & Sander, 2012, 2015) to determine whether gaze cues can modulate the contextual effect induced by happy faces at the conscious level. Another possible reason is that, in our experiment, the averted gaze of the target face can bias the perceived emotion to be more fearful (Adams & Kleck, 2003), which may somewhat dilute the effect of the happy context.

Despite that there have been some implications on the role of personality traits in contextual influences (Lee et al., 2012), empirical evidence is still lacking (Wieser & Brosch, 2012). The present study made an initial effort on this topic and showed that trait anxiety did influence the nonconscious affective contextual effect, especially in a threat-related context. One may argue that the current results can be simply accounted for by existing findings that observers with higher anxiety levels are more sensitive to the invisible fearful context and detect the potential threat more automatically (Bar-Haim et al., 2007; Beck & Clark, 1997; Etkin et al., 2004; Fox, 2002). However, those findings are insufficient to explain the gaze modulation effect that we observed, as for both gaze conditions, the observers were exposed to the same fearful context. Another possibility is that high trait anxiety is associated with increased sensitivity to gaze direction cues conveyed by fearful faces, resulting in the fear- and anxiety-specific gaze modulation effect. There seems to be evidence that trait anxiety augments the gaze cueing effect for fearful faces (Fox et al., 2007; Mathews et al., 2003). Nonetheless, a recent study using a large sample of participants did not observe such a modulation effect (Talipski et al., 2021). An alternative account is that people with higher trait anxiety levels are more inclined to integrate socially related information (i.e., the target and contextual faces linked by gaze cues) automatically, especially when there was invisible fear, thus leading to the nonconscious contextual modulation. Future studies are needed to examine these possibilities.

While the current results did not enable us to directly reveal the neural mechanism of the observed gaze modulation on the affective contextual effect, we suspect that it should involve the cooperation of several subcortical and cortical neural structures. Among them, the amygdala may be a core node given its broad engagement in social information processing and anxiety conditions. Firstly, the amygdala can be preferentially activated by invisible fearful faces (Jiang & He, 2006; Morris et al., 1999; Öhman, 2005; Whalen et al., 1998), probably through a fast subcortical pathway bypassing the primary visual cortex (LeDoux, 1996; Öhman, 2002). Furthermore, it is sensitive to social interactive information (Kujala et al., 2012; Sinke et al., 2010; Vrticka et al., 2013), and exhibits distinct activation modes when the emotion (e.g., facial expression) and social interaction information (e.g., gaze orientation) are combined (N'Diaye et al., 2009). In addition, the amygdala is intensely associated with social disorders including clinical or non-clinical anxiety (Bar-Haim et al., 2007; Etkin et al., 2004). Apart from the amygdala, cortical regions engaged by conscious emotion processing and social perception and cognition, such as the superior temporal sulcus (Deen et al., 2015), may also be involved in the affective contextual effect. Meanwhile, according to the social context network model (SCNM) proposed by Ibanez and Manes (2012), several frontal regions, including the orbitofrontal cortex, lateral prefrontal cortex, and superior orbital sulcus, as well as the parahippocampal gyrus located in the temporal lobes, may play critical roles in target-context integration (Baez et al., 2016; Kumfor et al., 2018). Whether and how these cortical regions and their interaction with the fear-specific subcortical pathway contribute to the nonconscious integration of socio-affective information will have to await further research.

5. Conclusions

In summary, the present study demonstrated that the affective contextual influence on facial emotion perception could occur without conscious awareness. Such an effect appeared to be threat and anxiety specific, as it only occurred for fearful context in individuals with high trait anxiety levels. These findings provide fresh insights into the automaticity and specificity of the affective contextual effect by situating it within a socially meaningful context. They also open new avenues for investigating the cognitive and neural mechanisms about how social and affective cues from different facial stimuli are automatically integrated to influence our perception of others' emotional states.

CRediT authorship contribution statement

Yujie Chen: Methodology, Software, Formal analysis, Investigation, Visualization, Writing – original draft. **Qian Xu:** Software, Writing – review & editing. **Chenxuan Fan:** Investigation. **Ying Wang:** Conceptualization, Methodology, Funding acquisition, Writing – review & editing. **Yi Jiang:** Funding acquisition, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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