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Is individual attentional bias positive or negative? It depends on trait anxiety

Liping Hu[1], Menghui Xiong[1], Jianhui Liang[1], Yan Huang[1,2,*]

[1]Shenzhen-Hong Kong Institute of Brain Science, Shenzhen Institutes of Advanced Technology, Chinese Academy of Sciences, Shenzhen, 518055, China
[2]School of Life Sciences, University of Chinese Academy of Sciences, Beijing, 100049, China

*Corresponding author. Shenzhen Institutes of Advanced Technology, Chinese Academy of Sciences, 1068 Xueyuan Avenue, Nanshan District, Shenzhen 518055, China. E-mail: yan.huang@siat.ac.cn

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Abstract

The debate over whether the general population shows positive or negative attentional bias persists. Some studies indicate that attentional bias varies individually rather than being a common trait. This study explored the relationship between individuals' trait anxiety and their attentional bias and its neural mechanisms. Seventy adults with varying trait anxiety levels participated in an emotional competition search task. In the competition condition, a happy and a angry face were presented among neutral faces, with one as the target and the other as the distractor; while in the non-competition condition, one happy or angry face was presented among the neutral faces. The N2pc component of event-related potential (ERP), an attentional selection index, was used to measure attentional bias. Results showed a significant correlation: lower trait anxiety was associated with a stronger positive bias, while higher levels were linked to a more negative bias. Importantly, this anxiety-associated attentional bias specifically manifested in bottom-up processes and the emotion-competition condition. Our research offers electrophysiological evidence indicating that individuals' trait anxiety is associated with the direction of attentional bias, and, for the first time, discloses its neural mechanism—emerging in stimulation-driven attentional processes, which has implications for cognitive interventions for anxiety disorders.

Keywords: attentional bias; trait anxiety; emotional competition; N2pc; ERP

Introduction

To deal with the overwhelming sensory information, our brains selectively prioritize specific information while disregarding the others. The emotional significance of sensory events is believed to exert a pivotal influence in the selection and inhibition of attentional resources (Vuilleumier 2005). However, it remains debated whether the attention processing of the general population exhibits a bias towards positive or negative stimuli (Kauschke et al. 2019, Xu et al. 2021). Recent studies have investigated the influence of trait anxiety on negative bias by comparing threatening stimuli with neutral ones and found a correlation between trait anxiety and negative bias, with higher levels of anxiety linked to more pronounced negative biases (Veerapa et al. 2020, Wieser and Keil 2020). A meta-analysis conducted by Bar-Haim et al. (2007) found that the combined effect size of the threat-related negative bias was significant in individuals with anxiety but not in nonanxious controls. Trait anxiety, a normally distributed trait, reflects a relatively stable and enduring tendency to experience anxiety (Spielberger et al. 1983, Vigneau and Cormier 2008). These observations suggest that attention bias may represent more of an individual characteristic rather than a collective trait within the population. This individualization may partially explain the inconsistencies regarding whether the general population exhibits a positive or negative bias. Therefore, this study aimed to investigate whether individuals' inclination towards positive or negative bias is associated with their level of trait anxiety and to elucidate the neural mechanisms underlying the individual attentional bias towards emotion by utilizing EEG. Specifically, the study aimed to identify the specific attentional processes in which the attentional bias occurs.

Attention is considered to contain top-down and bottom-up processes (Corbetta and Shulman 2002, Theeuwes 2010). Top-down attention refers to voluntary control based on current goals, such as attending to target stimuli, while bottom-up attention is involuntary in nature and driven primarily by the salience of stimuli, such as attending to prominent distractor stimuli. Previous electrophysiological studies have examined the mechanisms underlying attentional bias by investigating either the top-down or bottom-up attentional processes (Eimer and Kiss 2007, Reutter et al. 2017, Wieser et al. 2018). The dot-probe task, in which an angry or happy face and a neutral face are simultaneously presented, followed by a dot as a probe target, has been widely utilized for studying the neural mechanism of attentional bias (Torrence and Troup 2018). In this paradigm, emotional faces serve solely as distractors, allowing for the examination of only the bottom-up process of attention. Wieser et al. (2018) utilized the visual search paradigm to investigate attentional bias, focusing solely on the examination of emotional faces as targets, thus exclusively

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examining top-down attention processes without addressing bottom-up attention processes.

To date, there has been a scarcity of studies concurrently investigating both processes, leaving the question unanswered as to whether emotional bias is primarily associated with bottom-up stimulus capture or top-down attentional control. Therefore, our study employs EEG recordings to investigate the neural mechanisms underlying individual attentional bias by directly comparing top-down and bottom-up attentional responses to emotional stimuli.

To investigate the mechanism of attentional bias, our study employed a visual search paradigm to explore both top-down and bottom-up attention towards emotional faces, with emotional faces being presented as either targets or distractors. Desimone and Duncan (1995) proposed that increasing competition among multiple objects in a visual search task can enhance attentional biases. Therefore, we introduced a novel emotional competition search compared to the traditional non-competition search paradigm. In the traditional search, either a happy or an angry face is embedded among neutral faces (Feldmann-Wustefeld et al. 2011, Burra et al. 2017, Horstmann and Becker 2020). In the new competition condition, both a happy face and an angry face are simultaneously embedded among neutral faces to create an emotional competition pattern. We hypothesize that the emotional attentional bias will be more pronounced in the competition condition compared to the non-competition condition. Previous research has shown that the duration of stimulus presentation plays a crucial role in detecting attentional bias (Bar-Haim et al. 2007). For instance, Bantin et al. (2016) observed a decrease in bias towards threatening faces as the duration increased from short (<200 ms) to long (>1000 ms). This finding suggests that attentional bias mainly reflects early attentional processes, while longer presentation is influenced by later processes such as strategy and control processes. Therefore, in addition to manipulating emotional competition condition, we also employed a short stimulus duration (200 ms) to enhance the bias effect.

The N2pc, an ERP component originating from the posterior parietal cortex, is widely recognized as a reliable indicator of selective attention (Luck and Hillyard 1994, Eimer 1996). The N2pc component consistently demonstrates its superior sensitivity compared to behavioural measures when assessing attentional bias (Kappenman et al. 2014, 2015, Reutter et al. 2017, 2019). For example, Kappenman et al. (2014) discovered that while reaction time did not display a bias towards threatening images, the N2pc demonstrated a significant shift of attention towards threat. In the present study, we quantified individual attentional bias by measuring the difference in N2pc amplitude between angry and happy faces. A larger N2pc amplitude for happy faces represents a positive bias, and vice versa for a negative bias. Moreover, the N2pc can also be used to study whether attentional bias occurs in top-down or bottom-up attentional processes (Reutter et al. 2017, Wieser et al. 2018). When emotional faces serve as targets, the N2pc evoked by emotional faces represents the goal-driven/top-down attentional selection, and the N2pc difference between angry and happy faces reflects top-down attentional bias; conversely, when they act as distractors, it denotes stimulus-driven/bottom-up attentional bias.

Overall, the aim of this study was to investigate the relationship between trait anxiety and individual attentional bias, along with its underlying neural mechanisms. We recruited 70 healthy participants with varying levels of trait anxiety. We employed a novel visual search paradigm incorporating emotional competition, where happy and angry faces were simultaneously presented. This was compared to the classical non-competition condition in which only one emotional face (either happy or angry) was embedded among several neutral faces. We hypothesized that emotional competition conditions would enhance the detection of positive and negative biases. By examining the association between anxiety levels and individual attentional bias in both top-down and bottom-up processes, we aim to elucidate whether trait anxiety is associated with the direction of attentional bias and to identify the specific attentional processes involved in this association.

Material and methods

Participants

Seventy healthy Chinese undergraduate students aged between 18 and 30 (22 females) were recruited. They received a fixed compensation of 250 RMB for their time and participation in the research. All participants had normal or corrected-to-normal vision and were right-handed. Five subjects withdrew from the experiment, one citing personal discomfort, while the remaining four were excluded due to inadequate EEG data quality resulting from head movement and other factors. This resulted in a final sample size of 65 participants (17 females; mean age = 23 ± 2 years). The sample size was determined based on two previous studies investigating the correlation between the N2pc and trait anxiety, which employed sample sizes of 56 and 66, respectively (Kappenman et al. 2021, Hu et al. 2023). Taking into account potential exclusions, we opted for a sample size of 70 participants.

This study was conducted in accordance with the principles outlined in the World Medical Association Declaration of Helsinki and was approved by the Human Research Ethics Committee of the Shenzhen Institute of Advanced Technology (SIAT), Chinese Academy of Sciences. Prior to their participation, all participants were provided with detailed information about the experimental procedures and provided written informed consent.

Questionnaire

The levels of trait anxiety in the participants were assessed using the State-Trait Anxiety Inventory (STAI; Spielberger et al. 1983), a widely utilized self-evaluation questionnaire for measuring trait anxiety. Higher scores on the STAI indicate elevated levels of trait anxiety. The trait-anxiety scores of the participants ranged from 23 to 64, with a mean of 41 and a standard deviation of 10, which aligns with established norms for the general population (Spielberger et al. 1983). To ascertain the reliability of trait anxiety reports employing the STAI, Cronbach's alpha was computed (Booth et al. 2017, Steinweg et al. 2021). Cronbach's alpha for the STAI-T yielded a value of 0.901, indicating robust internal reliability of scale scores in this study.

Stimuli and procedures

The facial stimuli used in the experiment were selected from the Karolinska Directed Emotional Faces database (Lundqvist et al. 1998). The dataset consisted of 12 facial identities, with an equal distribution of six male and six female faces. Each identity had three different facial expressions: happy, angry, and neutral. To minimize any potential influence stemming from hair, neck, or background elements, all images were cropped at the hairline. Furthermore, to eliminate any confounding factors related to colour perception variations among participants, grayscale versions of the stimuli were employed while ensuring that their average luminance remained consistent throughout.

Each participant completed two search tasks, with one task involving the search for happy faces and the other for angry faces.

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Both tasks were identical except for their different targets, and the order of these tasks was counter-balanced among participants. The arrangement of the face display is depicted in Fig. 1. In each search display, six faces (equally distributed between male and female) were presented along a virtual circle with a radius of 6°. Two faces were positioned along the vertical centreline. There were two emotional competition conditions: competition condition (occurring in half of the trials) where a happy face, an angry face, and four neutral faces were simultaneously presented; non-competition condition where only one emotional face (either happy or angry, each occurring in a quarter of the trials) was randomly presented alongside five neutral faces. The positions of the six faces and emotional competition conditions were randomized across trials. Each task comprised 960 trials, resulting in a total of 1920 trials.

During the experimental procedure, the stimuli were presented on a 100-Hz monitor against a black background. Participants viewed the monitor from a distance of 80 cm. A gray fixation cross was consistently displayed at the centre of the screen throughout the experiment. Each trial commenced with a central fixation point lasting for 500 ms, followed by an immediate presentation of a search display for 200 ms. Participants were instructed to maintain their gaze fixated on the central point and respond promptly by pressing either the left or right button to indicate whether or not they detected the target stimulus. They were given 2 seconds to

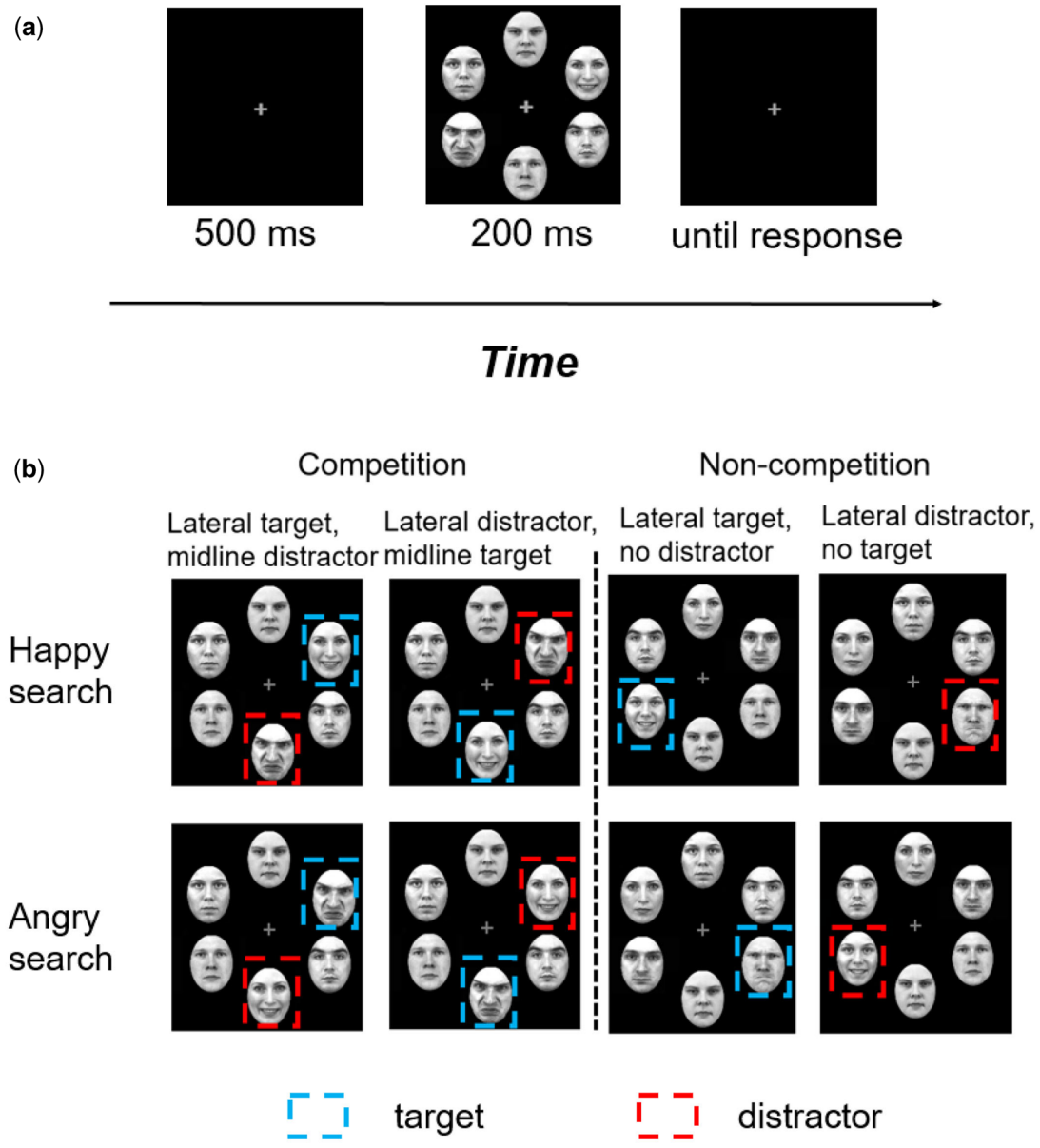


Figure 1. Experimental procedure and example stimuli. (a) Experimental procedure. Participants were instructed to engage in a visual search task aimed at identifying either a happy or an angry face. The order of the happy face search task and the angry face search task was counterbalanced across participants. (b) Example stimuli. The stimuli used for both the happy and angry search tasks were identical, with only the task demands differing between them. Two emotional competition conditions were randomly presented during each trial: in the competition condition, both a happy and an angry face were simultaneously displayed; whereas in the non-competition condition, either a happy or an angry face was shown exclusively. Each participant completed two search tasks, with their order being balanced across participants. In the happy face search task, participants had to identify happy faces as targets while ignoring any emotional distraction caused by angry faces; conversely, in the angry face search task, they had to identify angry faces as targets while disregarding any emotional interference from happy faces.

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provide their response after being presented with each search display. Reaction times (RTs) were recorded to assess participants' response speed and efficiency.

EEG recording and analysis

EEG data were collected using a 64-channel system (BrainAmp MR32, Brain Products GmbH) with a sampling rate of 1000 Hz. The reference electrode was placed at FCz, and the impedance was maintained below 5 kΩ. Offline EEG processing and analysis were conducted utilizing MATLAB and the EEGLAB toolbox. The recorded EEG signals were resampled to 250 Hz and underwent band-pass filtering using a non-causal two-way least-squares FIR filter with a cutoff range of 0.1–40 Hz and a roll-off rate of 12 dB/octave. The signals were then re-referenced to the average of the left and right mastoid channels. To remove artifacts related to eye blinks, horizontal eye movements, and heartbeats, independent component analysis (ICA) was performed using the BINICA routine in EEGLAB. Components associated with these artifacts were identified and subsequently removed based on their spatial, spectral, and temporal characteristics. The analyzed epochs ranged from 200 ms before stimulus onset to 500 ms after stimulus onset, with a pre-stimulus window of 200 ms used for baseline correction. To further eliminate horizontal eye movements, trials with blinks and vertical eye movements exceeding ±70 μV at Fp1/Fp2 channels and horizontal eye movements exceeding ±30 μV at F9/F10 channels were excluded. Approximately 0.8% of trials were rejected based on these criteria. For the subsequent ERP analyses, there were over 100 valid trials for each condition.

The N2pc components were obtained by subtracting ipsilateral ERPs from contralateral ERPs with respect to the location of stimulus of interest (the target or the distractor). The N2pc evoked by the target was extracted from trials with a centreline distractor and lateral target, or no distractor and lateral target. Distractor-evoked ERPs were extracted from trials involving a centreline target and lateral distractor, or no target and lateral distractor (refer to Fig. 1b). For measuring the N2pc, electrode sites P7, PO7, P8, and PO8 were selected as they exhibited the largest amplitudes for the component (see Fig. 2). In accordance with previous relevant studies on visual search (Gaspar and McDonald 2014, 2018, Hu et al. 2019, 2023, Luo et al. 2019), the target- and distractor-evoked N2pc time window was separately selected based on the peak (i.e. negative extreme points of the difference waves during 150–450 ms) of the averaged difference waves across all participants and conditions, with a window duration of 40 ms centred around the peak latency. In our study, the time window for target-evoked N2pc was observed to be 315–355 ms, while that of distractor-evoked N2pc was found to be 300–340 ms. For each participant and condition, the amplitudes of the target-evoked and distractor-evoked N2pcs were computed as the mean values within the respective time windows. The peak latency of N2pc was defined as the time point corresponding to the peak of the difference waves for each participant under each condition within a time window of 150–450 ms. Additionally, to further minimize the possibility of a spurious positive finding (Gaspar and McDonald 2018), we conducted analyses of signed areas measured in wider time windows (200–400 ms) subsequent to the peak-amplitude analyses (see supplementary materials).

Data analysis

Data analysis mainly comprises two relatively independent parts: (i) Population level analysis. This part of the analysis was mainly to detect whether the variable competition affected attention to the targets or the distractors. Additionally, to observe whether there was an emotional bias of attention at the population level, so as to facilitate comparison with previous studies. We examined the effects of stimulus (target vs. distractor), competition (competition vs. non-competition), and emotion (happy vs. angry) on N2pc amplitudes and latency using a three-way repeated measures analysis of variance (ANOVA). Moreover, in order to test whether task order and individual anxiety level affected population-level attention, we further performed a four-way analysis of covariance (ANCOVA) incorporating task order (happy face search vs. angry face search) as a within-subject factor and anxiety levels as a continuous covariate. Detailed results of ANCOVA are provided in the supplementary materials. (ii) Individual level analysis. To investigate how individual anxiety levels affect attentional bias, we conducted Pearson's correlation analyses to explore potential associations between anxiety scores and ERP measures. *P*-values were adjusted using the false discovery rate (FDR) method at a threshold of 0.05 (Benjamini and Hochberg 1995) to control for Type I errors. Additionally, Fisher's r-to-z transformation (Steiger 1980, Lee and Preacher 2013) was employed to compare correlation coefficients using the online calculator available at https://quantpsy.org/corrtest/corrtest2.

To further examine the consistency of the various measurements within an individual, we also assessed the internal consistency reliability of behavioural and ERP measures with a split-half approach, where the correlation between averages of odd- and even-numbered trials was determined and corrected using the Spearman-Brown prophecy formula (Kappenman et al. 2021).

Results

ERP results

Population level analysis

We measured attention on the target or the distractor by the peak amplitude and latency of the N2pc component. As depicted in Fig. 2a and b, both happy and angry faces, whether presented as targets or distractors, elicited a significant N2pc component under both competition and non-competition conditions (one sample t-test, *ps* < 0.001). To examine the influence of stimulus (target vs. distractor), competition (competition vs. non-competition), and emotion (happy vs. angry) on mean N2pc induced in the general population, a three-way ANOVA was conducted on mean peak amplitudes and latency, respectively. The results of peak amplitudes revealed that the main effect of competition was significant ($F(1, 62) = 14.818$, $P < .001$, $\eta^2 = 0.188$), showing a smaller amplitude in the competition condition as compared with the non-competition condition. Additionally, although the main effect of stimulus was not significant ($P = .529$), the interaction between stimulus and competition was significant ($F(1, 62) = 7.233$, $P = .009$, $\eta^2 = 0.102$). Post-hoc comparisons revealed that in the non-competition condition, targets evoked significantly larger N2pc amplitudes than distractors ($P = .035$), reflecting a clear goal-driven attentional advantage. However, this advantage was eliminated under competition, where target- and distractor-evoked N2pc amplitudes did not differ significantly ($P = .131$). This pattern indicates that the presence of a competing emotional stimulus effectively captures attention, thereby reducing the resources available for target selection. The main effect of emotion was not significant ($F(1, 62) = 3.351$, $P = .072$, $\eta^2 = 0.05$); however, there was a positive bias tendency, indicating that happy faces elicited larger peak amplitudes compared to angry faces, suggesting a weak positive bias at the population level. Also, emotion exhibits no significant interaction with other

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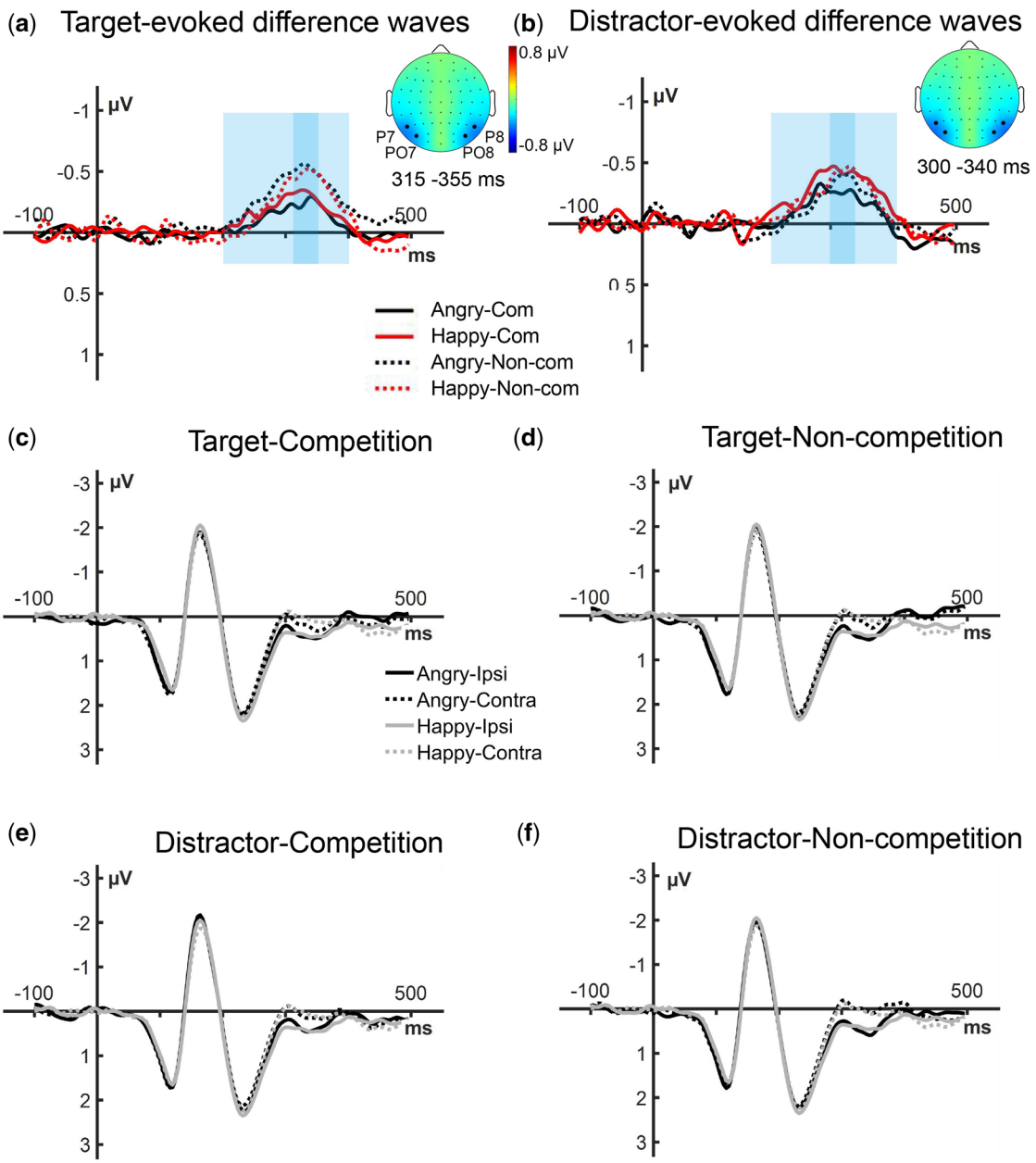


Figure 2. N2pc-based attentional bias and their correlation with trait anxiety levels ($n = 65$). (a, b) The N2pc evoked by emotional faces as targets (a) and distractors (b). Contralateral-minus-ipsilateral difference waveforms of happy faces (red line) or angry faces (black line) are shown in the competition condition (solid line) and non-competition conditions (dotted line). The light blue shading indicates the time window used for area amplitude measurement (200–400 ms), while the blue shading marks the window for peak amplitude measurement (target-evoked: 315–355 ms; distractor-evoked: 300–340 ms). The topographic maps illustrate the average N2pc across these four conditions within the specified time windows of the N2pc peaks. (c–f) ERP waveforms recorded contralaterally and ipsilaterally to the angry or happy faces. We present the contralateral (dotted line) and ipsilateral (solid line) waveforms evoked by happy faces (gray line) or angry faces (black line) as targets in both the competition condition (c) and non-competition condition (d), as well as waveforms evoked by distractors in the competition condition (e) and non-competition condition (f).

variables (*ps* > 0.1), suggesting that the population-level attentional bias was not affected by the other factors. Nevertheless, the results of the ANCOVA with anxiety level as a covariate reveal a significant four-way interaction among anxiety level, stimulus, competition and emotion ($P = .039$), suggesting that anxiety level exerts a significant influence on the effect of these factors on attention. In summary, the aforementioned results imply that at the population level, no robust attentional bias was present, and competition significantly modulated attention, with its effect varying on the attention of the target and the distractor.

In addition to the peak amplitude approach, we also employed the signed area method with a broader time window (200–400 ms) to calculate the size of N2pc. This area-based amplitude is considered to be capable of accommodating greater inter-participant variability in the timing of ERP components. The results of the area amplitude analyses were consistent with those of the peak amplitude analyses (see supplementary materials).

The peak latency of the N2pc elicited by target or distractor faces was analyzed. The same three-way ANOVA was performed with the predictors of stimuli, competition, and emotion. The results revealed that the main effects of three factors and their interactions were not significant (*ps* ≥ 0.149), suggesting that these factors had no impact on N2pc latency.

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Individual level analysis

The primary objective of this study is to investigate whether positive or negative bias is associated with the level of individual trait anxiety. Hence, we further conduct correlation analyses between individual attentional bias and their trait anxiety level under the four conditions (competition × stimulus), respectively. The attention bias was computed by subtracting the N2pc amplitude elicited by happy faces from that induced by angry faces. Top-down and bottom-up attentional processes were respectively explored through target- and distractor-evoked N2pc. The results revealed that regarding the target-evoked N2pc, no significant correlations existed between attentional bias and anxiety level, both in the competition ($r=-0.056$, $P=.660$, Fig. 3a) and non-competition conditions ($r=-0.077$, $P=.541$, Fig. 3b). These findings suggest that top-down attentional bias did not vary with trait anxiety level. However, regarding the distractor-evoked N2pc (Fig. 3c and d), a significant correlation between attentional bias and trait anxiety level in the competition condition was observed ($r=-0.392$, $P=.001$, FDR-corrected $P=.004$), whereas no significant correlation was found in the non-competition condition ($r=0.001$, $P=.992$). We further conducted statistical analyses to compare the correlation coefficients. For the distractor-evoked N2pc, the correlation between anxiety level and attentional bias was significantly more pronounced in the competition condition compared to the non-competition condition ($z=-2.33$, $P=.020$). Moreover, under the competition condition, the correlation coefficient for the distractor-evoked N2pc was significantly stronger than that for the target-evoked N2pc ($z=-2.16$, $P=.030$). For the area amplitudes of N2pc, we obtained consistent results, demonstrating a significant correlation between anxiety level and distractor-evoked N2pc ($r=-0.316$, $P=.010$), while no other significant correlations were identified (see supplementary materials). These findings imply that the attention bias of individuals is associated with their level of trait anxiety, and this correlation predominantly emerges in the bottom-up attention process. Moreover, the competition between positive and negative emotional faces is beneficial for the observation of this correlation.

Correlation analysis was also carried out on the peak latency of target-evoked and distractor-evoked N2pc to examine the association between individual attentional bias and their trait anxiety

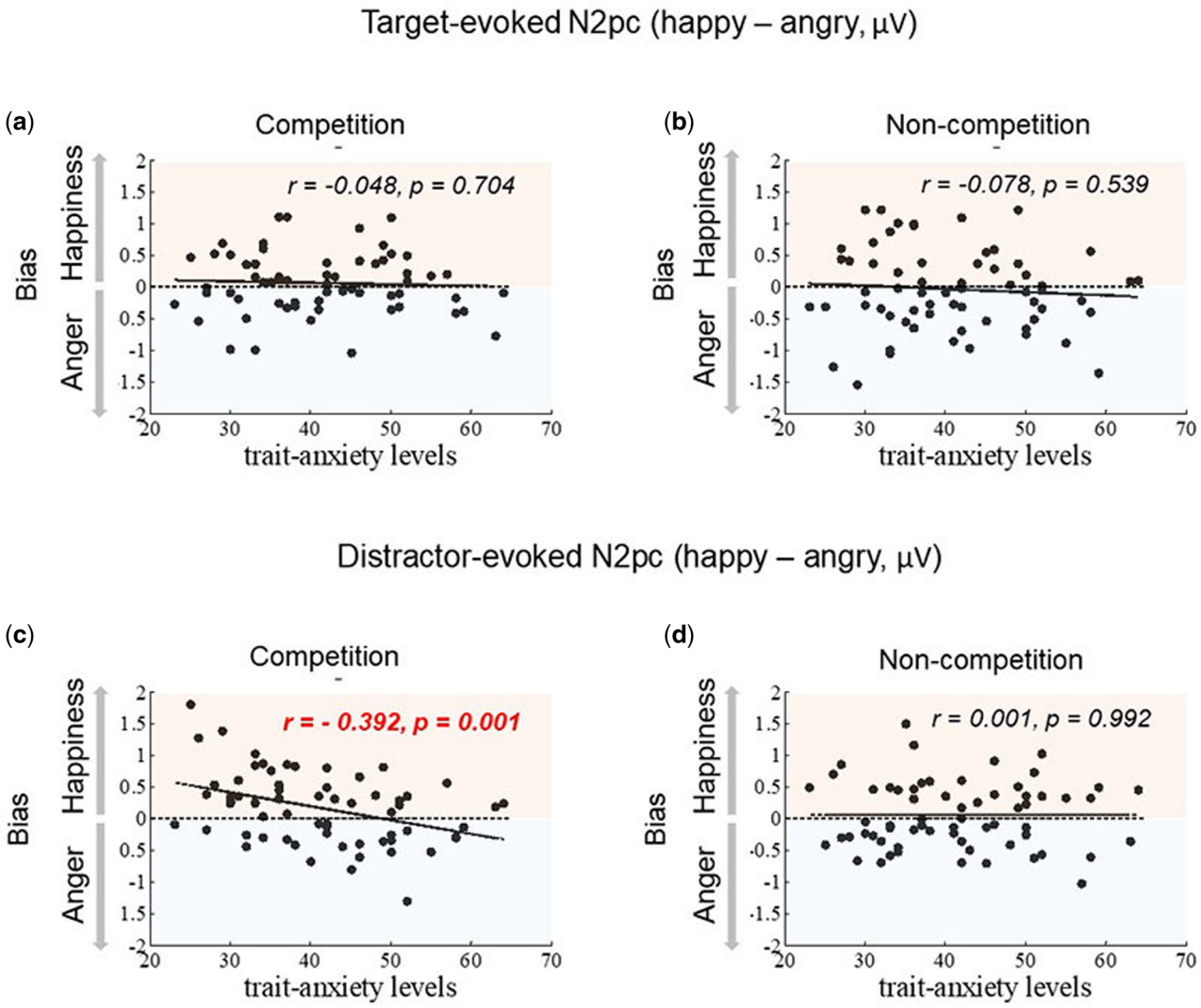


Figure 3. Attentional bias was quantified by calculating the difference in the peak amplitude of the N2pc elicited by angry and happy faces. When emotional faces served as targets, no significant correlations were found between attentional bias and trait-anxiety levels under both competition (a) and non-competition conditions (b). Nevertheless, when emotional faces acted as distractors, a significant correlation emerged between attentional bias and trait-anxiety levels specifically in the competition condition (c), while no significant correlation was observed in the non-competition condition (d).

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level. The results indicated no significant correlation either for target- or distractor-evoked N2pc under competition or non-competition conditions (*ps* ≥ 0.124).

Behaviour results

The average hit rate for the target ranged from 65% to 70%, which aligns with the level of acuracy observed in previous visual search studies involving a presentation duration of 200 ms for faces (Feldmann-Wustefeld et al. 2011). A two-factor ANOVA was conducted to examine the effects of emotion (happy face search vs. angry face search) and competition (competition vs. non-competition). The results revealed a significant main effect of competition (competition vs. non-competition: 66.2% ± 1.6% vs. 69.5% ± 1.6%, $F(2, 64) = 41.892$, $P < .001$, $\eta_p^2 = 0.396$), while the main effect of emotional and their interaction were not significant (*ps* ≥ 0.073), indicating an interference effect from distractors in the competition condition. These findings suggest the absence of top-down attentional bias in behaviour, which aligns with our electrophysiological results.

Similarly, the RT data were subjected to a 2-way ANOVA. Only the main effect of competition was found to be significant (competition vs. non-competition: 578 ± 24 ms vs. 570 ± 23 ms, $F(2, 64) = 5.747$, $P = .019$, $\eta_p^2 = 0.082$), while the main effect of emotion and the interaction were not significant (*ps* ≥ 0.246). Both accuracy and RT results indicate the absence of a top-down attentional bias, which aligns with our EEG findings. In addition, we examined whether N2pc-based attentional bias scores—calculated across target/distractor conditions and competition/non-competition conditions—were associated with behavioural bias scores (defined as the angry-minus-happy difference) in the corresponding conditions. No significant correlations were found between any N2pc-based attentional bias score and its paired behavioural bias score (all *ps* ≥ .196). This pattern suggests a potential dissociation between neural indices of attentional bias and overt behavioural performance.

Internal consistency reliability of behavioural and ERP measures

We initially assessed the internal consistency reliability of behavioural and ERP measures. The internal consistency reliability of behavioural and ERP measures was evaluated using a split-half approach, wherein we determined the correlation between averages of odd- and even-numbered trials and subsequently corrected it utilizing the Spearman-Brown prophecy formula (Kappenman et al. 2021). The Spearman-Brown corrected correlations for behavioural and ERP measures were all statistically significant (all $r > 0.837$, all *ps* < 0.001). These results indicate that both behavioural and ERP measures in this study exhibit robust internal reliability.

Discussion

The aim of this study was to investigate the association of trait anxiety between individual attentional bias and its neural correlates. Employing an ERP indicator of selective attention, our findings revealed a significant association between individuals' attentional bias and their levels of trait anxiety. Specifically, individuals with lower anxiety levels exhibited a stronger positive bias, whereas those with higher anxiety levels demonstrated a more pronounced negative attentional bias. These results suggest that attentional bias is individualized and is associated with varying levels of trait anxiety. Furthermore, we observed that the correlation between trait anxiety and attentional bias is predominantly evident in the bottom-up attentional process rather than the top-down attentional process. Notably, it is worth highlighting that the trait anxiety-associated attentional bias was solely evident in conditions involving emotional competition but disappeared when emotional faces were presented alone.

As discussed in recent reviews by Kauschke et al. (2019) and Xu et al. (2021), there is an ongoing debate on whether the general population exhibits a positive or negative bias. Previous studies have reported that trait anxiety affects the extent of negative bias, as evidenced by Dennis and Chen (2009) and Berggren and Eimer (2021). In contrast, we observed a tendency towards positive bias throughout the entire population ($P = .072$). To explore this further, we stratified participants into three groups based on anxiety levels—low, moderate, and high—for subgroup analyses (Table S2, see online supplementary material for a colour version of this table). Results indicated that both the low and moderate anxiety groups exhibited a positive bias, whereas the high anxiety group showed a negative bias; notably, significant difference emerged only between the high- and low-anxiety groups. Additionally, trait anxiety scores in the sample exhibit a normal distribution, as confirmed by the Jarque-Bera test ($P = .158$). These findings suggest, to some extent, that the weak positive bias observed in the overall sample may reflect a broader population characteristic, though further verification with a larger sample size is required. Even so, when considered alongside our current findings—specifically, positive bias in individuals with lower anxiety and negative bias in those with higher anxiety—attentional bias appears more strongly linked to individual traits. This individual-level variability, in turn, undermines the stability of any proposed population-level attentional bias.

Previous studies have identified a relationship between anxiety and negative bias towards threat (Salahub and Emrich 2020, Veerapa et al. 2020); however, our research extends beyond these findings. By utilizing both negative and positive face stimuli, we discovered that as trait anxiety levels increased among participants, there was a noticeable shift from a positive attentional bias to a negative one. To investigate whether this change in attentional bias was driven by attention to happy or angry faces alone, we conducted a correlation analysis between trait anxiety and N2pc responses elicited by happy or angry faces, respectively (Table S1, see online supplementary material for a colour version of this table). We observed a correlated tendency between trait anxiety and N2pc amplitude for happy face distractors ($r = 0.242$, $P = .052$) and for angry face distractors ($r = -0.234$, $P = .061$) in the competitive condition. When compared to the stronger correlation between anxiety and the N2pc difference between happy and angry faces, these findings suggest that anxiety-related attentional bias is not solely influenced by one type of emotional stimulus. Instead, it reflects a dynamic interplay between attention directed toward both positive and negative stimuli, which varies with levels of trait anxiety. In summary, anxiety-related attentional biases arise from a shift in the balance of attention toward positive and negative stimuli. Our findings offer fresh insights into the neural mechanisms underlying attentional bias in individuals with differing levels of trait anxiety.

In our study, we observed the effect of trait anxiety on attentional bias when emotional faces served as distractors rather than targets, suggesting that this effect predominantly manifests in the bottom-up attentional process rather than the top-down process. Previous investigations have primarily focused on a single attentional process. For instance, some prior research exploring the bottom-up process has reported attentional bias towards negative stimuli (Reutter et al. 2017, Berggren and Eimer 2021). Conversely,

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other studies investigating the top-down process have found attentional bias towards general emotional stimuli without specific emphasis on negative or positive stimuli (Wieser et al. 2018). In contrast, our study directly compares the top-down and bottom-up attentional processes within the same experimental context, thereby providing a distinct advantage in elucidating the predominant mechanism underlying attentional bias. By concurrently observing these two attentional processes, we reveal that the primary source of attentional bias originates from the bottom-up attention process. Similarly, a behavioural study on visual search examined the attentional bias towards emotional faces as both task-related and task-independent stimuli. The results indicated that trait anxiety primarily influenced the attentional bias in task-independent situations, highlighting its influence on bottom-up attentional process (Dodd et al. 2017). Essentially, these findings suggest that stimulus-driven ("bottom-up") processes may be more indicative of anxiety traits than goal-oriented ("top-down") processes.

It was observed that the association between trait anxiety and attentional bias exclusively manifested itself in the condition of positive and negative emotional competition, while it disappeared in a non-competitive setting. This finding suggests the emotional competition is more effective in eliciting attentional bias, which aligns with previous behavioural observations (e.g. Pinkham et al. 2010). Previous EEG studies examining attentional bias have typically employed non-competitive paradigms in which angry or happy emotional faces were presented alongside neutral faces (Brosch et al. 2011, Liu et al. 2021). While these studies did observe a heightened N2pc response to emotional faces compared to neutral faces, no discernible distinction was detected between the effects of positive and negative emotions. Our electrophysiological investigation provides neural evidence that emotional competition elicits a heightened sensitivity towards attentional bias, thereby offering valuable insights for future research on this topic. Although non-competition trials were randomly interspersed with competition trials, in order to eliminate any potential inter-trial priming effects from exposure to a single emotional face in the non-competition trials, it is recommended that future research focus exclusively on competition conditions for a better exploration of emotional bias.

It is important to consider that the investigation of attentional bias can be influenced by a range of experimental stimuli, presentation conditions, and types of anxiety. For instance, Burra et al. (2016, 2017) utilized the visual search paradigm in their investigation of attentional bias; however, they observed that attentional bias was linked to distinct ERP components. Specifically, cartoon faces elicited N2pc components, while naturalistic faces evoked Pd components. Consequently, within the similar paradigm but with different stimulus types, they identified associations between N2pc and Pd and negative bias, respectively. Moreover, the duration of stimulus presentation may also induce different ERP components. In contrast to the findings of Burra et al. (2017), which reported that long-term exposure to emotional faces induced Pd, our current study observed that brief presentation of emotional faces for 200 ms elicited N2pc but not Pd. Additionally, different types of anxiety may have distinct influences on attentional bias. For example, in the dot-probe task using facial stimuli, it was observed that attentional bias towards threatening stimuli exhibited a correlation not with trait anxiety scores, but rather with levels of social anxiety (Kappenman et al. 2014, Reutter et al. 2017). Subsequent studies could further integrate diverse forms of anxiety and stimuli in order to elucidate the breadth of the present findings.

In terms of the association between trait anxiety and the bottom-up, stimulus-driven attentional capture, we propose a hypothesis that trait anxiety influences this process through selection history. Our attention is more likely to be drawn towards objects that have been previously attended, which is the effect of selection history on attention. Previous studies have suggested that the selection history exerts an influence on attention through its impact on current objectives and the salience of stimuli (for a review, see Awh et al. 2012, Failing and Theeuwes 2018). Notably, both positive and negative emotional stimuli possess similar levels of salience in terms of their physical characteristics; therefore, they should elicit comparable degrees of attention capture without introducing any bias in the stimulus itself. However, the selection history of individuals with varying levels of trait anxiety diverges. Individuals exhibiting high trait anxiety demonstrate a heightened frequency of negative emotions in their choice history, whereas those with low anxiety exhibit a greater occurrence of positive emotions in their decision-making process (Vigneau and Cormier 2008). This disparity in selection history results in stimuli with comparable physical salience evoking distinct degrees of salience, thereby eliciting differential attention capture. That is, individuals with high anxiety have a positive bias while individuals with low anxiety have a negative bias. Furthermore, this attentional bias perpetuates and reinforces the individual's selection history. In the complex interplay between selection history and attention processes, attentional bias is further strengthened.

Repeated reinforcement of negative bias is widely acknowledged as a crucial factor in the development and maintenance of anxiety disorders (Bar-Haim et al. 2007, Hakamata et al. 2010). The extensively discussed attention bias modification (ABM) training aims to alleviate anxiety by attenuating negative bias (MacLeod et al. 2002, MacLeod and Clarke 2015, Mogg and Bradley 2018). This strategy involves instructing individuals to actively ignore threatening stimuli through top-down attentional control. Here, we propose that intentionally increasing the selection history of positive stimuli could potentially serve as an effective way to alleviate anxiety. Building upon our recent findings that individuals with low levels of anxiety exhibit a positive attentional bias, we propose the implementation of positive bias training (PBT) as a means to reverse negative bias. In PBT, we aim to counteract the negative bias in individuals with high anxiety by increasing their exposure to attentional capture scenarios involving positive stimuli, thereby augmenting the frequency of positive stimuli in their selection history. This approach has the potential to modify an individual's negative bias and may offer assistance in mitigating anxiety.

In conclusion, our findings provide valuable electrophysiological evidence that underscores the role of individual trait anxiety level in shaping attentional bias and elucidate the predominant mechanism underlying such biases. Future research could investigate the potential impact of this enduring negative attentional bias on the occurrence and progression of emotion-related disorders, as well as explore cognitive training interventions aimed at ameliorating the negative bias.

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Author contributions

Liping Hu and Yan Huang designed the study, analyzed the data, and wrote the paper. Menghui Xiong and Jianhui Liang conducted the experiments. All authors contribute to and have approved the final text.

Supplementary data

Supplementary data is available at SCAN online.

Conflict of interest: None declared.

Data availability

We report how we determined our sample size, all data exclusions, all manipulations, and all measures in the study. All data are available on OSF at https://osf.io/38p6a/. This study was not preregistered.

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