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Neurophysiological correlates for dynamic variability between vigilance and avoidance in test anxiety

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ABSTRACT

Attention bias (ABs) to threat is essential in the etiology and maintenance of test anxiety. However, little is known about the attention pattern of ABs in test anxiety. The stimulus duration affects the attention pattern in anxiety. Thus, the present research combined the dot-probe paradigm and event-related potentials (ERPs) and varied the stimulus duration (100 ms or 500 ms) to test the ABs in test anxiety. Consequently, both groups showed a threat N2pc in 100 ms and 500 ms duration, suggesting that both groups allocated attention to the test-related threat. However, in the 100 ms duration, the high test-anxious (HTA) group had smaller target-elicited P1 and greater target-elicited N2 in the threat-congruent condition than in the neutral condition. In the 500 ms duration, an earlier threat N2pc and a threat PD followed a greater target P1, and smaller target N2 were pronounced in the HTA group. The current results provided electrophysiological evidence that the HTA group kept a dynamic attention pattern that fluctuated shift between vigilance and avoidance in the 100 ms and 500 ms duration. The HTA group was more vigilant than the LTA group in the 500 ms duration when strategic attention was concerned, proposing that vigilance in test anxiety was not an automatic process.

1. Introduction

Test anxiety is situation-specific trait anxiety (Spielberger et al., 1976), where individuals are characterized by excessive fear or worry of poor performance and resulting anxiety-related cognitive, physiological, or emotional reactions before, during, and after test situations (Burcaş et al. (2020); von der Embse et al., 2018; Zeidner, 1998). High test-anxious (HTA) individuals consider anything concerning the test or evaluative situation as a threat and have been associated with attention bias (ABs) to test-related threats (Dong et al., 2017; Jastrowski Mano et al., 2018), which is an essential factor in the etiology and maintenance of anxiety (Bar-Haim et al., 2007; Colin et al., 2019; Goodwin et al., 2017; McNally, 2018). Also, attentional bias modification (ABM) has been proposed as an efficient enhancing treatment for anxiety reduction (Bar-Haim, 2010) and a prevention tool for decreasing anxiety susceptibility (e.g., MacLeod et al. (2016); Reutter et al., 2019).

Researchers have mixed findings on ABs in anxiety. Some assumed that ABs in anxiety are expressed in a consistent manner, which is characterized as either vigilance or maintenance of threats (e.g., Boll et al., 2016; Capriola-Hall et al., 2020; Cui et al., 2020; Wermes et al., 2018). Other research suggested dynamic ABs variability fluctuating toward or away from threatening information from moment to moment (Evans et al., 2020; Zvielli et al., 2015; Zvielli et al., 2014). The ABs in test anxiety have been widely proved in a consistent manner. For example, previous research with a dot-probe task found that HTA students exhibit ABs to test-related words unique in the evaluative situation (Putwain et al., 2011). Moreover, Jastrowski Mano and colleagues (2018) reported ABs toward school-related images without the evaluative stressor. Zhang et al. (2018) concluded that high test-anxious individuals showed ABs by enhanced N2 amplitude toward the test-related threat. However, Liu et al. (2015) indicated a difficult disengagement when test-related threats appeared as an invalid cue in an emotional spatial cue task.

The threat discrimination and cognitive control model (TDCM) suggests that the dynamic variability in ABs may be attributed to the higher sensitivity to threats and poorer cognitive control in anxiety

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(Dennis-Tiwary et al., 2019). The higher sensitivity to threats and poor cognitive control in test anxiety has been proved as the HTA individuals were more vigilant to the low-threatening information and showed inhibition deficits in the flanker and Stroop task (Dong et al., 2017; Wei et al. (2021); Wei et al. (2021); Zhang et al., 2019). According to the TDCM (Dennis-Tiwary et al., 2019), the higher sensitivity to threats and poorer cognitive control in test anxiety possibly resulted in a dynamic attention pattern. Previous research did not temporally distinguish the patterns of ABs in test anxiety and failed to find a dynamic pattern (e.g., Jastrowski Mano et al., 2018; Liu et al. (2015); Putwain et al., 2011; Zhang et al., 2018). Event-related potentials (ERPs) findings suggested that ABs to threats may rapidly fluctuate from initial vigilance to avoidance under 500 ms (Buodo et al., 2010). Thus, the sensitive physiological ERPs could temporally measure the dynamic pattern of ABs anxiety over the time course of the assessment. It would be crucial to examine whether the HTA individuals showed a dynamic ABs variability with the temporal ERPs.

Previous research suggests that automatic vigilance to threats is the main factor in the vulnerability to anxiety disorders (Beck & Clark, 1997; Mathews & Mackintosh, 1998). However, Hu et al. (2021) indicated that early vigilance to the test-related threat is specified in the task-relevant condition, suggesting that vigilance in test anxiety may not be automatic. A few competing items in a visual search task increase the perceptual load and greater stimulus eccentricity, affecting the early orienting to threat (Richards et al., 2014). Thus, the previous finding may be caused by the specific task used. Besides, a 100 ms duration probably reflects automatic initial shifts in attention, and multiple attentional shifts can occur within 500 ms stimulus presentation (Cooper & Langton, 2006). Thus, 100 ms and 500 ms durations could assess both the automatic covert attention and the controlled overt attention (Cooper et al., 2006; Gronchi et al., 2018; Mingtian et al., 2011). The present research would vary the stimulus duration (100 ms/500 ms) to investigate whether vigilance in test anxiety is automatic. Previous findings commonly show ABs toward threatening information at shorter stimulus durations (<500 ms Bar-Haim et al., 2007), whereas no bias or threat avoidance appears at longer durations (500 ms; Gronchi et al., 2018; Mogg et al. (2016)). Thus, it is unclear whether the stimulus duration would affect attention patterns in test anxiety.

ERPs measures can help elucidate the cognitive processes in the temporal processing stream. Previous research found a dynamic ABs variability in anxiety relies on a single response time measure per trial (e.g., Zvielli et al., 2014). The behavioral index concerning several processing stages (e.g., action preparation, motor execution) may interfere with assessing ABs towards the threat (Wieser et al. (2020)). Thus, the present research aimed to characterize ABs patterns in test anxiety by combining the temporal ERPs components and classic dot-probe tasks. The cue and probe ERPs are analyzed separately in the dot-probe task paradigm. Amplitude or latency modulations of the cue ERPs may indicate ABs occurring at the early processing stages. In contrast, the probe ERPs may indicate ABs occurring at later processing stages (Gupta et al., 2019). For the cue-locked ERPs, we would analyze the threat N2pc (The posterior contralateral N2, N2pc) and PD (Distractor positivity, PD). The N2pc reflected attentional selection of the stimuli, which occurs 200–300 ms after the onset of a search display (e.g., Hickey et al., 2006; Luck et al. (1994))). The N2pc was more remarkable to the attended than the unattended stimulus (Holmes et al., 2009; Kappenman et al., 2014). Attentional selection of threat or salient distractor indexed by N2pc is magnified for individuals with high anxiety levels (Gaspar et al. (2018); Salahub et al., 2020). The PD is an enhanced positive component elicited over posterior brain areas contralateral to the distractor 300 and 400 ms after search display onset. The PD has been used to measure active inhibition/ suppression of the distractor (e.g., Hickey et al., 2009; Sawaki et al., 2012). Previous research on PD found that anxiety was related to the reactive suppression of conditioned threats (Kappenman et al., 2021). In addition to recording the cue-elicited N2pc and PD, we also analyzed the target P1, N2, and P3. The P1 amplitudes reflect attentional and arousal differences in early-stage perceptual processing (Luck, 2006). The N2 is an early negative-going visual component appearing just after the P1. Greater amplitudes for this component have been linked to discriminating between stimuli (Ehrlich et al., 2015). The P3 appears as a positive deflection at the posterior parietal 300 ms after stimulus onset, particularly sensitive to attention selection (Polich, 2007).

The TDCM suggests that the higher sensitivity to threats and poorer cognitive control shown in anxious individuals contributed to the dynamic variability of ABs in anxiety (Dennis-Tiwary et al., 2019). Moreover, previous research proved that HTA individuals have a higher sensitivity to test-related threats and deficits in cognitive control (Dong et al., 2017; Wei et al., 2021a; Wei et al., 2021b; Zhang et al., 2019). Accordingly, we hypothesized that the HTA group would express a dynamic attention pattern to the test-related threat. For 100 ms duration, the HTA group would show vigilance towards the test-related threat by showing a threat cue-elicited N2pc and rapid attentional avoidance after the vigilance by offering a smaller target P1. For 500 ms duration, the HTA group would show a dynamic vigilance-avoidance pattern by a threat cue-elicited N2pc and followed a PD in a cue display and a greater target P1 with a smaller target N2 in a probe display. Besides, previous research suggested that the automatic vigilance of the threat is the main characteristic of anxiety (Beck et al., 1997; Mathews et al., 1998). Thus, we predicted that the HTA group would emerge earlier threat cue-elicited N2pc than the low test-anxious (LTA) group in 100 ms duration.

2. Method

2.1. Participants

Initially, 386 students volunteered to fill out the Chinese version of the test anxiety scale (TAS-C)[1] (Wang, 2001). TAS-C scores of 20 or above were considered for HTA (89) and 12 or lower for LTA (76) (Newman, 1996). In line with this, we obtained 159 participants, 83 in the HTA and 76 in the LTA group. Other students refused to participate in the experiment after they knew the details of the electroencephalography (EEG) experiments. Fifty-two participants (age range: 18–25) divided into one HTA and one LTA group attended the final experiments, with 26 participants in the HTA group (15 males, M TAS-C scores = 24.38; SD TAS-C scores =4.03, M age = 21.23; SD age = 1.48) and 26 in the LTA group (11 males, M TAS-C scores = 8.92, SD TAS-C scores =3.41, M age = 21.12; SD age = 1.88). An independent-sample t-test conducted with TAS-C scores showed that the scores of the HTA group were significantly higher than the LTA group, $t(50) = 14.94$, $p < 0.01$.

All participants who attended experiments gave informed consent and were paid ¥ 40 for their time. All were naïve to the purpose of the study and reported having normal or corrected to normal vision and declared themselves free of neurological disorders. All procedures were in accordance with the ethical principles of human experimentation and with the approval of the ethical committee of the University.

2.2. Stimulus, apparatus, and procedure

Thirty test-related words and 30 neutral words were used as word pairs. Word pairs were presented between the left and right sides in Song font size 36 and were 4 cm apart. These words were selected from the Test Anxiety Word System, which provided a standard set of test-

[1] TAS-C was revised from the test anxiety scale (TAS) by Sarason (1978). There are 37 items of TAS-C, which are scored using the two true/false answer categories. The total score of TAS-C ranges from 0 to 37, while the higher score indicates higher test anxiety. The reliability and validity have been established in previous research (Wang, 2001). Moreover, the internal reliability coefficient for the present study was 0.82.

relevant stimuli with normative ratings on test relevance, arousal, and familiarity. The test-related word is a Chinese two-character noun used to describe testing or evaluative situation (i.e., "test papers"). The neutral word is a Chinese two-character noun for daily supplies (i.e., "chairs") (Yu et al., 2011). A paired-sample t-test found that the test-relevant scores of test-relevant words were significantly higher than test-irrelevant words (4.62 vs. 2.89), $t(52) = 11.94$, $p < 0.001$. No differences were found with the scores of familiarities, $t(58) = 1.17$, $p = 0.245$; 5.97 vs. 6.09).

Participants took part in the experiment individually. As shown in Fig. 1, each trial started with a 1° × 1° fixation cross on the center for 750–1350 ms, followed by a word pair for 100 ms or 500 ms. The location of the neutral words in each trial was equally likely to be left or right. After the cue and a 300 ms interval, a target (one upper or lower arrow) was presented with a duration of 150 ms. In threat-congruent trials, the target appeared at the location previously occupied by the test-related words; in threat-incongruent trials, the target was previously occupied by the neutral words. In the neutral condition (the word pairs were the neutral word), the target equally appeared on the left and right. In the response trials (10%), targets were either upper or lower arrows (upper or bottom pointing with equal regularity) again decided randomly at the outset but presented in the same sequence for each participant. Participants were instructed to press the F key in response to an upper arrow key and the J key in response to a bottom arrow. In the trials without response (90%), the target was the "< >," and participants were instructed not to respond.

Participants had to complete 400 trials with a word pair consisting of a test-related word and a neutral word in each duration (200 trials for threat-congruent condition and 200 trials for threat-incongruent condition). The word pair in the other 200 trials consisted of two neutral words. Each participant did 24 practice trials and performed 1200 formal trials. Participants had a break every 100 trials.

2.3. Electrophysiology

The electrophysiological (EEG) data were using 66 Ag-AgCl scalp electrodes placed according to the International 10/20 system at a 1000 Hz sampling rate with "Neuroscan (USA)" amplifiers. The impedances were kept below10 kΩ. The electrode placed on the left mastoid served as a reference during recording and re-referenced offline to the average left/right mastoid. The horizontal and vertical EOG signals were measured from electrodes 1 cm lateral to the outer canthi of each eye and from an electrode placed below the right eye.

The EEG data analyses were performed in MATLAB using EEGLAB Toolbox (Delorme et al., 2004) and ERPLAB Toolbox (Lopez-Calderon et al., 2014) and resampled offline to 500 Hz. Continuous EEG data were filtered with a 30 Hz low-pass filter and a 0.1 Hz high-pass filter.

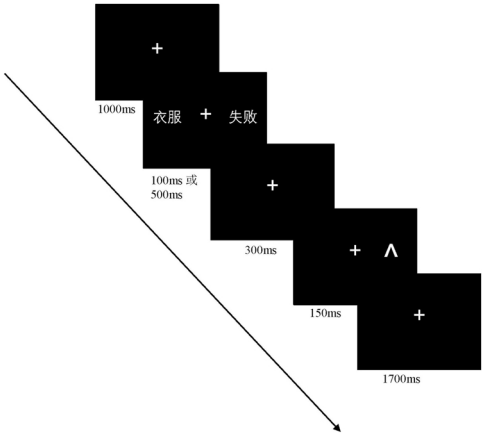

Fig. 1. Example of the flow of events on trial.

Cue-locked epochs were computed with a 500 ms epoch starting 100 ms before and ending 400 ms after the onset of the word pair in the 100 ms duration. A 600 ms epoch starting 100 ms before and ending 500 ms after the beginning of the word pair was computed in the 500 ms duration. Target locked epochs were extracted from 100 ms before target onset, lasting 600 ms in both 100 ms and 500 ms duration. Baselines were computed using 100 ms pre-stimulus. Independent component analysis (ICA) was applied to correct eye blinks and horizontal eye movements. The criterion for excluding an ICA component was the consistency between the shape, timing, and spatial location of the component. Finally, trials with amplitude values exceeding ± 75μV at any electrode were rejected.

Four participants (2 participants of the HTA group and 2 participants of the LTA group) were excluded from the final analyses as more than 25% of trials were rejected. The average percentage of abandoned trials was 11% (range 1.6–23.47%).

We selected five pairs of sites (P3 and P4, P5 and P6, P7 and P8, PO3 and PO4, and PO7 and PO8) for calculating N2pc and PD as these posterior electrodes usually selected by previous research (Luck, 2011; Wieser et al., 2018). The N2pc and PD were quantified based on mean amplitudes within three successive time windows (early N2pc: 180–250 ms; late N2pc: 250–320 ms; PD: 360–430 ms) (Holmes et al., 2009). The N2pc and PD were quantified as the contralateral-minus-ipsilateral difference waveform of the test-related threat cue. A significant effect of contra-laterality would indicate the presence of the N2pc and PD. For the cue-locked ERPs, we aimed to distinguish the ERPs data between the threat-present and neutral conditions data. Thus, we combined the threat-congruent and threat-incongruent condition data and regarded them as the threat-present condition. Accordingly, we conducted 2 (group: HTA, LTA) × 2 (contra-laterality: contralateral, ipsilateral) × 2 (condition: threat-present, neutral) repeated measures ANOVA for the cue-locked N2pc and PD in 100 ms and 500 ms duration. Onset latencies of the N2pc were measured using jack-knife sub-averages (each sub-averaged based on data sets of each group) following conventional jack-knife methods to correct statistical values. Onset latency was defined as when the activity reached 75% of its peak amplitude. Before testing for significance, the t-values should be adjusted according to (Ulrich et al. (2001)).

$$t_c = t/(n\text{-}1)$$

The t was the t-value of t-tests, and n was the number of samples.

For the target-locked ERPs, we analyzed the P1 (140–190 ms), N2 (150–250 ms), and P3 (350–500 ms) components. The time window is selected around the peak of each ERPs component (Pintzinger et al., 2017). The electrode site was selected from posterior electrodes suggested by previous studies (Pintzinger et al., 2017; Santesso et al., 2008). To increase analysis sensitivity and because of differential hemispheric effects, we combined electrodes into three clusters: posterior left (P3, P7, O1, PO3, PO7) and posterior right (P4, P8, O2, PO4, PO8) (Wieser et al., 2018). We did a 2 (group: HTA, LTA) × 2 (stimulus duration: 100 ms, 500 ms) × 3 (condition: threat-congruent, threat-incongruent, neutral) repeated-measures ANOVAs for the target-locked P1, N2, and P3 separately for 2 clusters.

Data were analyzed with SPSS 23.0. A p-value less than 0.1 but greater than 0.05 was considered marginally significant (e. g., Gaspelin et al. (2018)). Pairwise comparisons and simple effects were conducted with a Bonferroni correction. To avoid contamination from the motor response, ERPs analyses were restricted to trials without manual response to avoid contamination from the motor response (Holmes et al., 2008).

3. Results

3.1. Behavioural data

Firstly, we analyzed the accuracy of the task. A 2 (group: HTA, LTA) × 2 (stimulus duration: 100 ms, 500 ms) × 3 (condition: threat-congruent, threat-incongruent, neutral) repeated-measures ANOVAs of accuracy found the main effect of the stimulus duration, $F(1, 46)= 5.15$, $p = 0.028$, $\eta_p^2 = 0.103$, the accuracy with 100 ms duration ($M = 99.6\%$, 95% CI = [99.48%, 99.72%]) was greater than 500 ms duration ($M =$ 99.43%, 95% CI = [99.27%, 99.59%]). No other significant effects were observed (see Table 1), $F \leq 1.9$, $p \geq 0.175$, $\eta_p^2 \leq 0.04$.

Secondly, we analyzed the response times (RTs) of 10% trials with motor response. A 2 (group: HTA, LTA) × 2 (stimulus duration: 100 ms, 500 ms) × 3 (condition: threat-congruent, threat-incongruent, neutral) repeated-measures ANOVAs of RTs found the main effects of the stimulus duration, $F(1, 46)= 9.47$, $p = 0.004$, $\eta_p^2 = 0.171$, the RTs with 100 ms duration ($M = 670$, 95% CI = [641,698]) were shorter than 500 ms duration ($M = 692$, 95% CI = [660,724]). The main effects of group were significant, $F(1, 46)= 4.72$, $p = 0.035$, $\eta_p^2 = 0.093$, the RTs of the HTA group ($M = 649$, 95% CI = [608,691]) were faster than the LTA group ($M = 712$, 95% CI = [671,754]). No other significant effects were observed, $F \leq 2.051$, $p \geq 0.134$, $\eta_p^2 \leq 0.043$.

3.2. ERP data

3.2.1. The Cue-locked early N2pc

The grand average cue-locked ERPs are shown in Fig. 2. In the 100 ms duration, a 2 (group: HTA, LTA)× 2 (contra-laterality: contralateral, ipsilateral) × 2 (condition: threat-present, neutral) repeated measures ANOVA for early N2pc amplitude revealed a significant main effect of contra-laterality, $F(1, 46)= 7.21$, $p = 0.01$, $\eta_p^2 = 0.136$. The condition × Contra-laterality interaction was significant, $F(1, 46)= 4.85$, $p = 0.033$, $\eta_p^2 = 0.095$. Further simple effect analysis found a significantly enhanced contralateral effect in the neutral condition (contralateral: $M = -1.54$, 95% CI = [−2.07, −1.01], $p = 0.005$; ipsilateral: $M = -1.38$, 95% CI = [−1.91, −0.86]), whereas no significant contralateral effect emerged in the threat-present condition (contralateral: $M = -1.46$, 95% CI = [−1.96, −0.98], $p = 0.506$; ipsilateral: $M = -1.45$, 95% CI = [−1.94, −0.95]). No other significant effects were observed, $F \leq 2.16$, $p \geq 0.149$, $\eta_p^2 \leq 0.045$.

In the 500 ms duration, a 2 (group: HTA, LTA)× 2 (contra-laterality: contralateral, ipsilateral) × 2 (condition: threat-present, neutral) repeated measures ANOVA for early N2pc had no significant effects, $F \leq 0.93$, $p \geq 0.34$, $\eta p^2 \leq 0.02$.

3.2.2. The Cue-locked late N2pc

In the 100 ms duration, a 2 (group: HTA, LTA)× 2 (contra-laterality: contralateral, ipsilateral) × 2 (condition: threat-present, neutral) repeated measures ANOVA for late N2pc amplitude revealed that a significant main effect of contra-laterality, $F(1, 46)= 17.33$, $p < 0.01$, $\eta_p^2 = 0.274$. The condition × Contra-laterality interaction was significantly, $F(1, 46)= 6.47$, $p = 0.014$, $\eta_p^2 = 0.123$, further simple effect analysis found no significant enhanced contralateral effect in the neutral condition (contralateral: $M = -0.25$, 95% CI = [−0.7, 0.2], $p = 0.181$; ipsilateral: $M = -0.18$, 95% CI = [−0.63, 0.26]), whereas a significant contralateral effect emerged in the threat-present condition (contralateral: $M = -0.39$, 95% CI = [−0.83, 0.06], $p < 0.001$; ipsilateral: $M = -0.15$, 95% CI = [−0.58, 0.28]). No other significant effects were observed, $F \leq 1.66$, $p \geq 0.204$, $\eta_p^2 \leq 0.035$.

In the 500 ms duration, a 2 (group: HTA, LTA) × 2 (contra-laterality: contralateral, ipsilateral) × 2 (condition: threat-present, neutral) repeated measures ANOVA for late N2pc amplitude revealed that a significant main effect of contra-laterality, $F(1, 46)= 4.27$, $p = 0.044$, $\eta_p^2 = 0.085$. The condition × Contra-laterality interaction was significant, $F(1, 46)= 5.09$, $p = 0.029$, $\eta_p^2 = 0.1$. Further simple effect analysis found no significant enhanced contralateral effect in the neutral condition (contralateral: $M = 1.08$, 95% CI = [0.59, 1.57], $p = 0.839$; ipsilateral: $M = 1.07$, 95% CI = [0.56, 1.57]), whereas a significant contralateral effect emerged in the threat-present condition (contralateral: $M = 0.94$, 95% CI = [0.44, 1.43], $p = 0.002$; ipsilateral: $M = 1.1$, 95% CI = [0.63, 1.58]). No other significant effects were observed, $F \leq 0.48$, $p \geq 0.494$, $\eta_p^2 \leq 0.01$.

An independent-sample t-test conducted for N2pc latency (HTA: $M =$294 ms, 95% CI = [294.81, 294], LTA: $M =$306 ms, 95% CI = [302.23, 310.61]) observed no significant differences between the HTA and LTA group in the 100 ms duration, $t_c(23) = -0.24$, $p = 0.8$, whereas the N2pc latency of the HTA group ($M =$288 ms, 95% CI = [287.72, 288.38]) was significantly earlier than the LTA group ($M = 315$ ms, 95% CI = [314.65, 315.08]) in the 500 ms duration, t_c (46) = −3.1, $p = 0.005$.

3.2.3. The Cue-locked PD

In the 100 ms duration, the target appeared during the time window of the PD. The cue-locked PD could be overlapped with the target ERPs, and we could not analyze the cue-elicited PD.

In the 500 ms duration, a 2 (group: HTA, LTA) × 2 (contra-laterality: contralateral, ipsilateral) × 2 (condition: threat-present, neutral) repeated measures ANOVA for PD amplitude observed a significant main effect of the condition, $F(1, 46)= 10.94$, $p = 0.002$, $\eta_p^2 = 0.192$. The Condition × Contra-laterality × Group interaction was significant, $F(1, 46)= 3.79$, $p = 0.058$, $\eta_p^2 = 0.076$. In the HTA group, no significant enhanced contralateral effect in the neutral condition (contralateral: $M = 1.06$, 95% CI = [0.23, 1.89], $p = 0.409$; ipsilateral: $M = 1.13$, 95% CI = [0.32, 1.94]), whereas a significant contralateral effect emerged in the threat-present condition (contralateral: $M = 0.89$, 95% CI = [0.01, 1.76], $p = 0.018$; ipsilateral: $M = 0.73$, 95% CI = [−0.15, 1.62]). No significant enhanced contralateral effect was found in the neutral (contralateral: $M = 0.86$, 95% CI = [0.04, 1.68], $p = 0.362$; ipsilateral: $M = 0.79$, 95% CI = [−0.02, 1.6]) and threat-present conditions (contralateral: $M = 0.61$, 95% CI = [−0.27, 1.49], $p = 0.644$; ipsilateral: $M = 0.58$, 95% CI = [−0.31, 1.47]) in the LTA group. No other significant effects were observed, $F \leq 1.78$, $p \geq 0.188$, $\eta_p^2 \leq 0.037$.

3.2.4. The target-locked P1

The grand average target ERPs components and the topographic scalp maps are shown in Fig. 3 and Fig. 5.

A 2 (group: HTA, LTA) × 2 (stimulus duration: 100 ms, 500 ms) × 3 (condition: threat-congruent, threat-incongruent, neutral) repeated-measures ANOVAs for P1 amplitude in the posterior left area found a marginally significant condition × stimulus duration interaction, $F(2, 92)= 2.84$, $p = 0.064$, $\eta_p^2 = 0.058$. Moreover, the condition × stimulus × group interaction was significant (see details in the left figure of Fig. 4A), $F(2, 92)= 4.44$, $p = 0.018$, $\eta_p^2 = 0.088$, no significant

Table 1
The accuracy (M(SE)) of the task.

	100 ms			500 ms		
Group	Threat-congruent	Threat-incongruent	Neutral	Threat-congruent	Threat-incongruent	Neutral
HTA	99.6%(0.001)	99.58%(0.001)	99.46%(0.001)	99.46%(0.001)	99.46%(0.001)	99.46%(0.001)
LTA	99.73%(0.001)	99.48%(0.001)	99.64%(0.001)	99.41%(0.001)	99.41%(0.001)	99.36%(0.001)

Note: HTA represents high test anxiety; LTA represents low test anxiety.

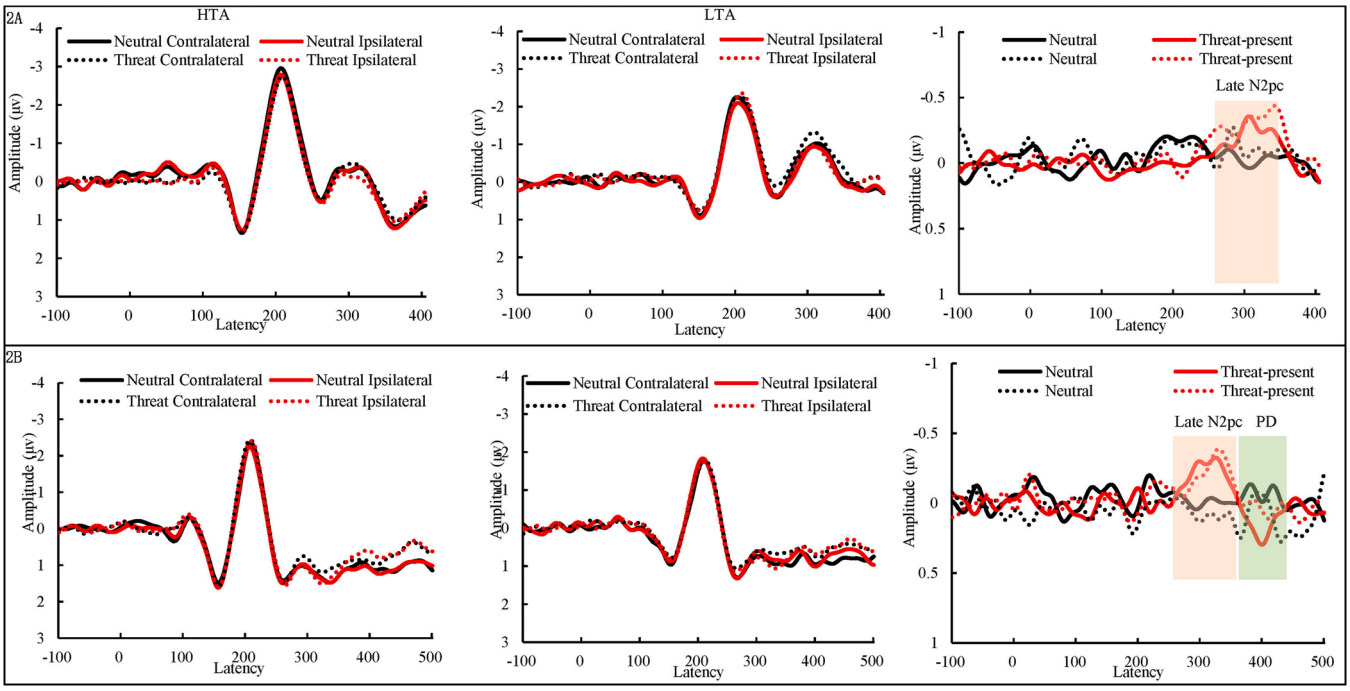

Fig. 2. shows the event-related potentials elicited by the cue display. Fig. 2 A shows the grand-averaged event-related potential waveforms recorded contralaterally and ipsilaterally to the threat cue for the 100 ms duration. Fig. 2B shows the grand-averaged event-related potential waveforms recorded contralaterally and ipsilaterally to threat cue for the 500 ms duration. The left figure shows the grand-averaged event-related potential waveforms for the HTA group. The middle figure shows the grand-averaged event-related potential waveforms for the LTA group. The right figure shows the contralateral-minus-ipsilateral (Contra-Ipsi) difference waveforms of the cue display (The full line shows the difference waveforms of the HTA group, and the dotted line shows the difference waveforms of the LTA group). Note: HTA represents high test anxiety; LTA represents low test anxiety.

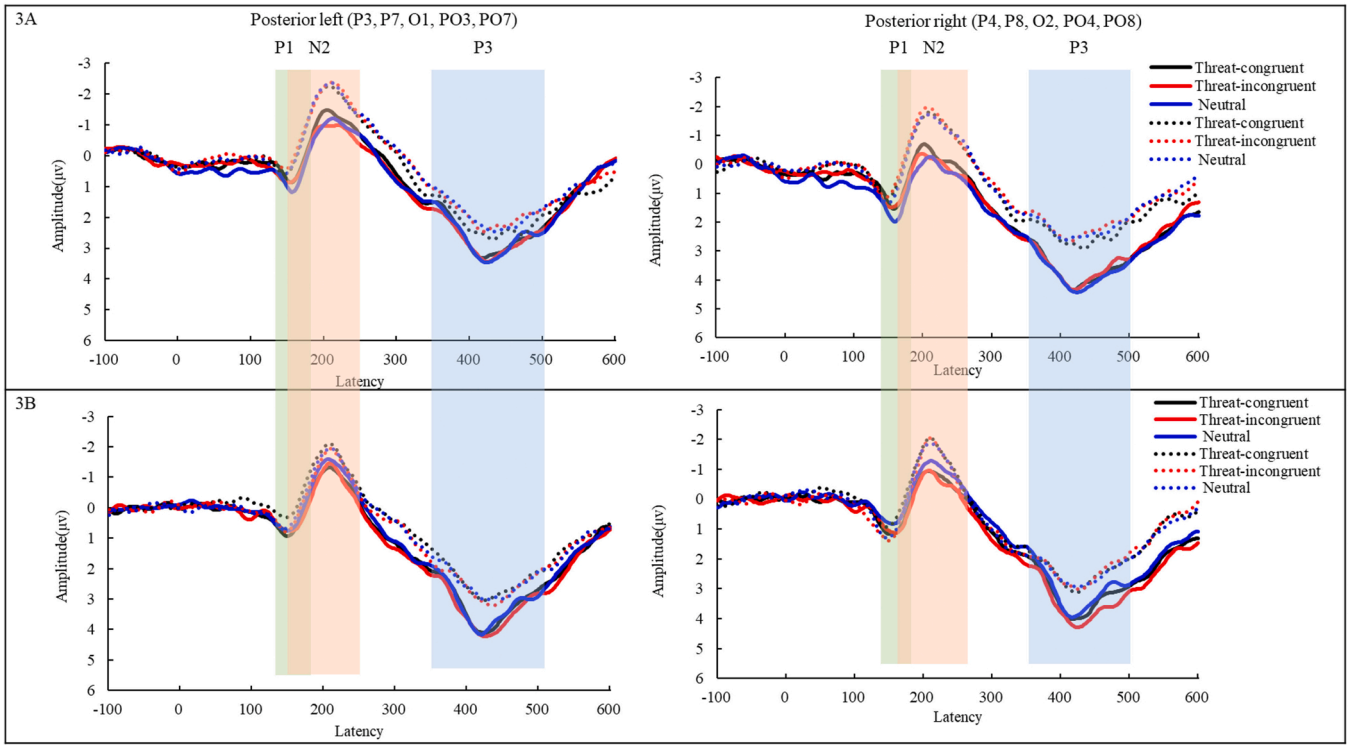

Fig. 3. shows the event-related potentials elicited by the target display. Fig. 3 A shows the grand-averaged event-related potential waveforms of the target for the 100 ms duration. Fig. 3B shows the grand-averaged event-related potential waveforms of the target for the 500 ms duration. The left figure shows the posterior left (P3, P7, O1, PO3, PO7) grand-averaged event-related potential waveforms of the target. The right figure shows the posterior right (P4, P8, O2, PO4, PO8) grand-averaged event-related potential waveforms of the target. The full line shows the grand-averaged event-related potential waveforms of the HTA group, the dotted line shows the grand-averaged event-related potential waveforms of the LTA group. Note: HTA represents high test anxiety; LTA represents low test anxiety.

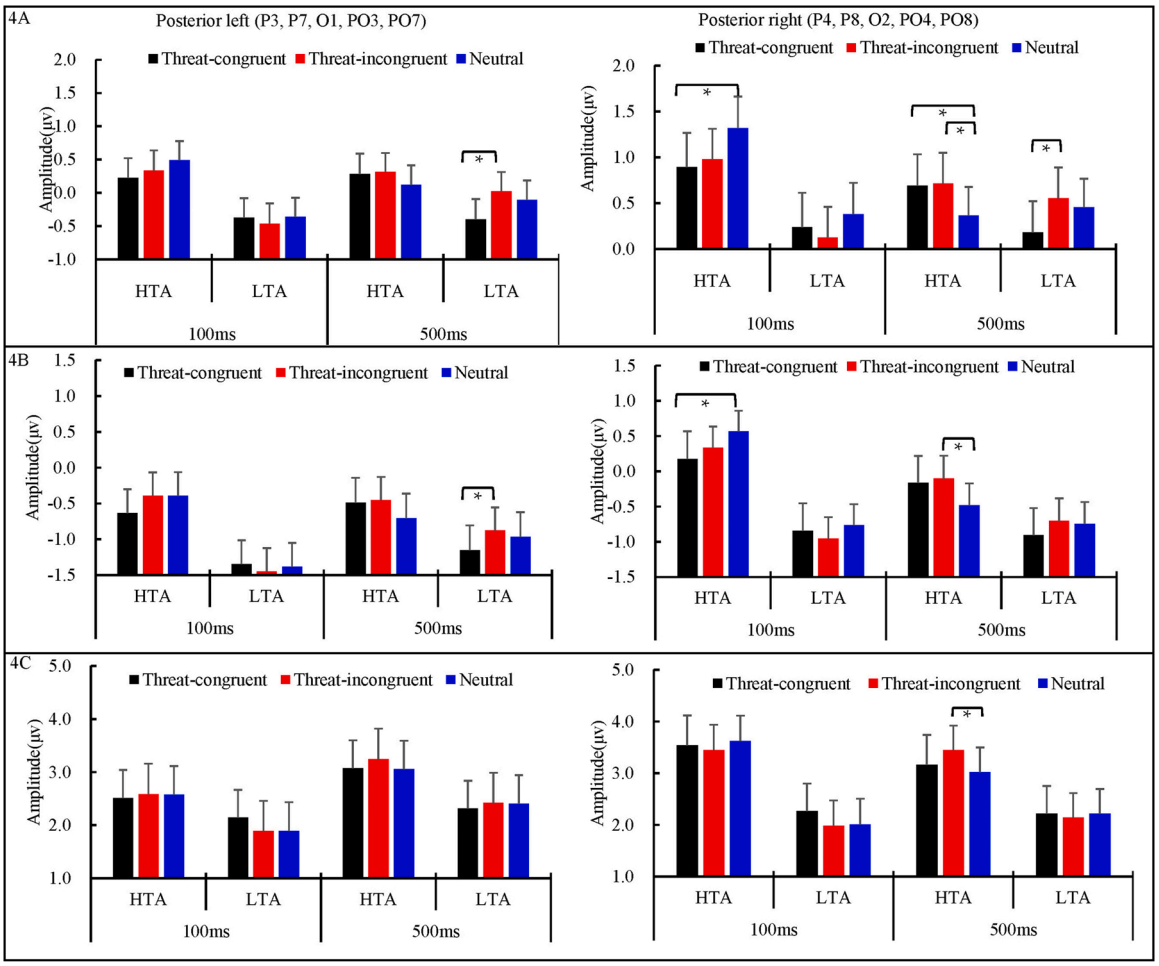

Fig. 4. shows the mean values of the target elicited event-related potential waveforms. Fig. 4A shows the mean values of the target P1 (140–190 ms) amplitude. Fig. 4B shows the mean values of the target N2 (150–250 ms) amplitude. Fig. 4C shows the mean values of the target P3 (350–500 ms) amplitude. The left figure shows the posterior left (P3, P7, O1, PO3, PO7) grand-averaged event-related potential waveforms of the target. The right figure shows the posterior right (P4, P8, O2, PO4, PO8) grand-averaged event-related potential waveforms of the target. Note: HTA represents high test anxiety; LTA represents low test anxiety.

differences were for the HTA group ($ps \geq 0.118$). For the LTA group, no differences were found in the 100 ms duration ($ps \geq 1$). In the 500 ms duration, the P1 amplitude in the threat-congruent condition ($M = -0.401$, 95% CI = [−1.02, 0.22]) was significantly smaller than in the threat-incongruent ($M = 0.03$, 95% CI = [−0.56, 0.6], $p = 0.002$) condition and showed a smaller trend than the neutral conditions ($M = 0.105$, 95% CI = [−0.69, 0.48], $p = 0.08$). No other significant effects were observed, $F \leq 2.884$, $p \geq 0.096$, $\eta_p^2 \leq 0.059$.

A 2 (group: HTA, LTA)× 2 (stimulus duration: 100 ms, 500 ms) × 3 (condition: threat-congruent, threat-incongruent, neutral) repeated-measures ANOVAs for P1 amplitude in the posterior right area found a significant interaction between condition and stimulus duration, $F(2, 92) = 6.95$, $p = 0.002$, $\eta_p^2 = 0.131$. The condition × stimulus duration × group interaction was significant (see details in the right figure of Fig. 4A), $F(2, 92) = 5.08$, $p = 0.008$, $\eta_p^2 = 0.099$. For the HTA group, the P1 amplitude of the neutral condition ($M = 1.319$, 95% CI = [0.63, 2.01]) was significantly greater than in the threat-congruent condition ($M = 0.89$, 95% CI = [0.22, 1.56], $p = 0.008$) and had a greater trend than of the threat-incongruent condition ($M = 0.98$, 95% CI = [0.29, 1.66], $p = 0.148$) in the 100 ms duration. In the 500 ms duration, the P1 amplitude of the neutral condition ($M = 0.364$, 95% CI = [−0.26, 0.99]) was smaller than the threat-congruent ($M = 0.7$, 95% CI = [0.01, 1.37], $p = 0.039$) and the threat-incongruent conditions ($M = 0.72$, 95% CI = [0.04, 1.39], $p = 0.045$). For the LTA group, no significant differences were found in 100 ms duration ($ps \geq 0.426$). The P1 amplitude of the threat-congruent condition ($M = 0.18$, 95% CI = [−0.5, 0.86]) was smaller than that of the threat-incongruent ($M = 0.55$, 95% CI = [−0.12, 1.22], $p = 0.023$) condition but showed no differences from the neutral condition ($M = 0.45$, 95% CI = [−0.18, 1.08], $p = 0.104$) in the 500 ms duration. No other significant effects were observed, $F \leq 1.839$, $p \geq 0.165$, $\eta_p^2 \leq 0.38$.

3.2.5. The target-locked N2

A 2 (group: HTA, LTA) × 2 (stimulus duration: 100 ms, 500 ms) × 3 (condition: threat-congruent, threat-incongruent, neutral) repeated-measures ANOVAs for N2 amplitude in the posterior left area found a significant condition × stimulus duration × group interaction (see details in the left figure of Fig. 4B), $F(2, 92) = 4.64$, $p = 0.012$, $\eta_p^2 = 0.092$. No differences were found for the HTA group, ($ps \geq 0.178$). For the LTA group, no differences were found in the 100 ms duration ($ps \geq 1$). In the 500 ms duration, the N2 amplitude of the threat-congruent condition ($M = -1.15$, 95% CI = [−1.86, −0.45]) was more negative than the threat-incongruent condition ($M = -0.88$, 95% CI = [−1.53, −0.23], $p = 0.026$) and showed no differences in the neutral condition ($M = -0.97$, 95% CI = [−1.67, −0.27], $p = 0.329$). No other significant effects were observed, $F \leq 1.51$, $p \geq 0.23$, $\eta_p^2 \leq 0.032$.

A 2 (group: HTA, LTA) × 2 (stimulus duration: 100 ms, 500 ms) × 3 (condition: threat-congruent, threat-incongruent, neutral) repeated-measures ANOVAs for N2 amplitude in the posterior right area found a significant interaction between condition and stimulus duration, $F(2,$

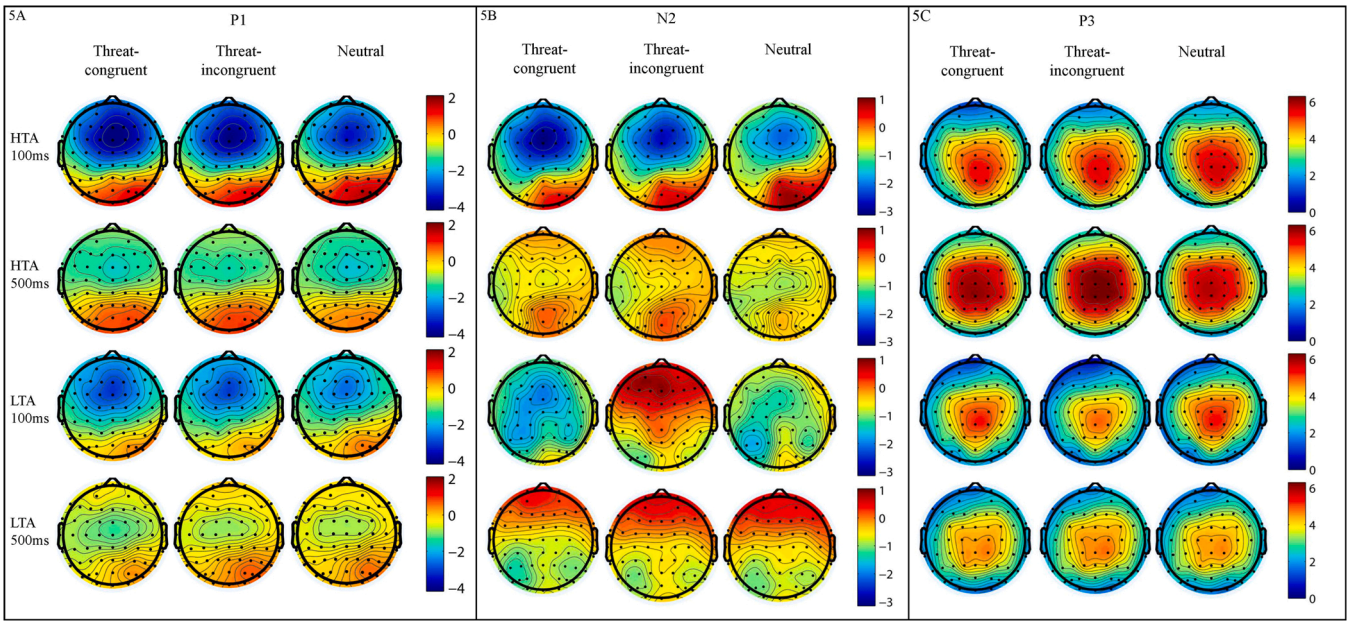

Fig. 5. shows the topography of the target elicited event-related potential waveforms. Fig. 5A shows the topography of the target P1 (140–190 ms) amplitude. Fig. 5B shows the topography of the target N2 (150–250 ms) amplitude. Fig. 5 C shows the topography of the target P3 (300–350 ms) amplitude. Note: HTA represents high test anxiety; LTA represents low test anxiety.

92)= 6.22, $p = 0.003$, $\eta_p^2 = 0.119$. Moreover, the condition × stimulus duration × group interaction was significant (see details in the right figure of Fig. 4B), $F(2, 92) = 4.83$, $p = 0.01$, $\eta_p^2 = 0.095$. For the HTA group, the N2 amplitude of the threat-congruent condition ($M = 0.17$, 95% CI = [−0.44, 0.79]) was more negative than the neutral condition ($M = 0.57$, 95% CI = [−0.03, 1.16], $p = 0.003$) and had no differences with the threat-incongruent condition ($M = 0.33$, 95% CI = [−0.29, 0.95], $p = 0.491$) in the 100 ms duration. In the 500 ms duration, the N2 amplitude of the neutral condition ($M = -0.49$, 95% CI = [−1.12, 0.15]) was more negative than the threat-congruent ($M = -0.17$, 95% CI = [−0.82, 0.49], $p = 0.051$) and threat-incongruent conditions ($M = -0.1$, 95% CI = [−0.73, 0.53], $p = 0.037$). For the LTA group, no significant differences were found ($ps \geq 0.393$). No other significant effects were observed, $F \leq 1.92$, $p \geq 0.172$, $\eta_p^2 \leq 0.04$.

3.2.6. The target-locked P3

A 2 (group: HTA, LTA) × 2 (stimulus duration: 100 ms, 500 ms) × 3 (condition: threat-congruent, threat-incongruent, neutral) repeated-measures ANOVAs for P3 amplitude in the left posterior area found no significant effects (see details in the left figure of Fig. 4C), $F \leq 2.53$, $p \geq 0.12$, $\eta_p^2 \leq 0.052$.

A 2 × 2 × 3 repeated-measures ANOVAs for P3 amplitude in the posterior right area found a marginally significant main effect of the group, $F(1, 46) = 4.02$, $p = 0.051$, $\eta_p^2 = 0.08$, the P3 amplitude of the HTA group ($M = 3.37$, 95% CI = [2.49, 4.25]) was greater than the LTA group ($M = 2.14$, 95% CI = [1.26, 3.01]). The condition × stimulus duration interaction was marginally significant, $F(2, 92) = 2.66$, $p = 0.075$, $\eta_p^2 = 0.055$. Moreover, the condition × stimulus duration × group interaction was marginally significant (see details in the right figure of Fig. 4 C), $F(2, 90) = 2.77$, $p = 0.068$, $\eta_p^2 = 0.057$. For the HTA group, no differences were found in the 100 ms duration ($ps \geq 0.654$). In 500 ms duration, the P3 amplitude of the threat-incongruent condition ($M = 3.44$, 95% CI = [2.41,4.48]) was greater than the neutral condition ($M = 3.02$, 95% CI = [2.05, 3.99], $p = 0.009$), and showed no differences in the threat-congruent condition ($M = 3.17$, 95% CI = [2.21, 4.12], $p = 0.199$). No other significant effects were observed, $F \leq 1.85$, $p \geq 0.163$, $\eta_p^2 \leq 0.039$.

4. Discussion

The present study combined the ERPs techniques with the dot-probe task and precisely characterized dynamic attention patterns in test anxiety. As a result, both groups showed a threat cue-elicited late N2pc in the 100 ms and 500 ms duration, and only the HTA group had a threat cue-elicited PD in the 500 ms duration. These results indicated attention vigilance for both groups and followed a form of threat avoidance in the 500 ms for the HTA group. The onset latency of the cue-elicited late N2pc for the HTA group was earlier than the LTA group in 500 ms duration. In contrast to the neutral condition, the HTA group exhibited a decreased target P1 amplitude and enhanced target N2 amplitude of the threat-congruent condition in the 100 ms duration and a greater target P1 amplitude and smaller N2 amplitude in the threat-congruent and threat-incongruent conditions in the 500 ms duration. The target-locked ERPs components revealed a greater target P1 amplitude of the threat-incongruent condition than the threat-congruent condition in the 500 ms duration for the LTA group. Besides, the parietal-right remained an augmented P3 amplitude of the threat-incongruent condition than the neutral condition for the HTA group.

In the 100 ms duration, the threat cue-elicited N2pc observed in both groups supported the idea that immediate attention allocation to the threat is a normal and adaptive phenomenon. Given the concise stimulus duration, these data align with the models of attention to the threat that have emphasized the evolutionary function of immediate attention to threat (Koster et al., 2005; Mogg et al., 1998). Following the threat cue-elicited N2pc, the HTA individuals decreased the target P1 amplitude and enhanced N2 amplitude in the threat-congruent condition. The P1 and N2 amplitude might reflect distinct aspects of spatial attention (Hillyard et al., 1994; Luck et al., 1994). The probe P1 reflects the sustained attention in the early perceptual process of the target, whereas the N2 demonstrates the later discrimination process within the focus of attention (Natale et al., 2006). It was indicated that HTA individuals showed reduced visual processing of the threatening cued locations at the early target processing and enhanced attendance later, suggesting that the HTA individuals alternated between vigilance and avoidance of the test-related threat.

Similarly, both groups attended to the test-related threat indexed by the threat cue-locked N2pc in the 500 ms duration. However, a threat

cue-locked PD emerged in the HTA group. PD is a specific index of attentional suppression to the attended location (Kappenman et al., 2021; Sawaki et al., 2012). These findings demonstrated that the HTA individuals showed rapid attention avoidance to the test-related threat after the initial orientation. For the target-locked ERPs, the greater P1 and smaller N2 amplitude found in HTA individuals could be the same as the enhanced P1 amplitude and attenuated negative components found in high-anxious individuals in previous research (Helfinstein et al., 2008; Holmes et al., 2008). The greater P1 amplitude seen in HTA individuals was signed as the enhanced sensory processing of the threat at the target display, possibly caused by the greater activation of the amygdala (Helfinstein et al., 2008; Holmes et al., 2008). The decreased N2 effects in HTA participants might suggest that attention avoidance was exerted following initial vigilance (Helfinstein et al., 2008; Holmes et al., 2008). Thus, the HTA group showed a dynamic pattern that fluctuated shift between vigilance and avoidance at the early (cue) and later processing (target) in the 500 ms duration.

Previous research proposed that individuals with greater emotion dysregulation exhibit dynamic ABs, characterized by dynamic variabilities between vigilance and avoidance (Bardeen et al., 2017). Overall, the present findings were consistent with this idea as HTA individuals varied between vigilance and avoidance in the 100 ms and 500 ms duration when the test-related threat appeared. The TDCM suggested that the higher sensitivity to threats and weakened cognitive control in anxiety contributed to the dysregulated threat responses and resulted in the dynamic variability in ABs over time (Dennis-Tiwary et al., 2019). The current study presented the test-related threat and neutral stimuli synchronously. The HTA individuals failed to distinguish between the threat and neutral stimuli, then showed vigilance and avoidance of the test-related threat back and forth. The dynamic variability between the vigilance and avoidance pattern potentially reflected the attention dyscontrol in test anxiety (e.g., Zvielli et al., 2014).

The target P1 of the LTA individuals was larger for the threat-incongruent condition than for the threat-congruent condition, confirming that test-related threats can affect spatial attention in LTA individuals (see Santesso et al., 2008). Previous research found that anxious individuals had more significant ABs toward threat-related information (Reutter et al., 2017; Salahub et al., 2020). However, we found that both groups allocated attention to test-related threats and showed no differences in the cue N2pc. In contrast to the LTA group, HTA showed attention avoidance after the initial vigilance. These findings were consistent with ideas linking anxiety to the avoidance behavior suggested by the previous research (Kappenman et al., 2021). Kappenman et al. (2021) demonstrated that anxious individuals might have a more aversive response to a threat and engage more cognitive resources to suppress or avoid threat-related stimuli. Previous research suggested that the enhanced posterior P3 indicated that more cognitive resources were being allocated toward the task-relevant but previously less perceived location to ensure the effective achievement of task goals and provide compensatory responses at the later stage (Cui et al., 2020; Liu et al., 2015; Zhang et al., 2017). The HTA group showed greater target P3 in the threat-incongruent condition for 500 ms duration. In the threat-incongruent condition, the HTA individual had to disengage the attention from the location of the test-related threat and orient to the target location. Zhang et al. (2019) indicated that HTA individuals consume more top-down attentional resources to process task-relevant information and inhibit interference in a Stroop task. Similarly, the greater target P3 supported the idea that the HTA individuals engaged more top-down cognitive resources to avoid task-irrelevant threats during more detailed and sustained processing stages for 500 ms duration.

Previous models suggest that automatic vigilance to threats is the main factor in the vulnerability to anxiety disorders (Beck et al., 1997; Mathews et al., 1998). However, the current findings indicated that the HTA individuals quickly attended the test-related threat only in 500 ms duration as the HTA group showed an earlier threat cue-elicited N2pc than the LTA group in the 500 ms duration and not in the 100 ms duration. Stimulus appeared 500 ms duration are supraliminal, which implies strategic attention processing that is effortful, intentional, and conscious (Cooper et al., 2006; Gronchi et al., 2018; Putwain et al., 2020). In other words, the results obtained in the 500 ms duration do not necessarily reflect automatic ABs to threat (Cooper et al., 2006). Thus, the current research was inconsistent with previous models (Beck et al., 1997; Mathews et al., 1998) and suggested that attention vigilance in test anxiety was not an automatic process (Hu et al., 2021; Putwain et al., 2020).

For the HTA group, the test-related threat elicited more significant effects indexed by the target P1, N2, and P3 amplitudes in right hemisphere locations. This lateralization in the emotional expression ERPs effects were consistent with previous findings that anxious individuals show enhanced attentional engagement to both happy and angry facial expressions, especially when they appear in the left visual hemifield (Wieser et al., 2018). The right hemisphere had superior visual processing during sustained alertness conditions (Wieser et al., 2018). The current findings were in accordance with the idea that the right hemisphere dominates the threat processing (Holmes et al., 2008; Najt et al., 2013).

Our study has some shortcomings that should be further investigated in future research. The dynamic attention pattern in test anxiety found in the current study showed in a dot-probe task, in which only one neutral item competed for attention resources with the test-related threat. Previous research suggested that visual display will affect the attention pattern in anxiety (Richards et al., 2014). When in a complex visual display, numerous competing stimuli would increase the perceptual load and result in greater stimulus eccentricity, affecting early orienting bias in anxiety. Thus, future studies would welcome exploring whether the dynamic attention pattern in test anxiety would be extended in a visual display with a large sample of stimuli.

The dynamic attention pattern that fluctuated between vigilance and avoidance in test anxiety is in line with empirical evidence suggesting attentional dyscontrol of threatening information may be critical to emotional dysregulation (e.g., Bardeen et al., 2017; Schafer et al., 2016). The current findings have several implications for the research concerning ABs in anxiety. Firstly, previous studies suggested ABs may be expressed in fluctuating patterns with attention toward or away from threat with the behavioral index computed by trial-level bias score (TL-BS) (Zvielli et al., 2015; Zvielli et al., 2014). The present neurophysiological component provided direct evidence for the dynamic time-course ABs variability in test anxiety and suggested that the observed effects of dynamic ABs in anxiety were not accounted for using a specific TL-BS computational methodology. Besides, the dynamic variability between vigilance and avoidance in test anxiety may provide a feasible empirical explanation of previous ABs heterogeneity in anxiety. Notably, previous research expressed either vigilance, avoidance, or no bias as the presence of dynamic ABs in anxiety, then responses in some trials terminated by the ABs toward the threat and some away from the threat, and canceled each other when averaged (e.g., Dennis-Tiwary et al., 2019). Additionally, previous research proposed threat-avoidance training based on the assumption that anxious individuals have an automatic tendency to attend preferentially to threats can reduce anxiety (MacLeod et al., 2015; MacLeod et al., 2002). However, we found that the dynamic ABs variability in test anxiety potentially suggested that the attention control training designed to reduce threat attentional dyscontrol (rapid shifts between vigilance and avoidance of the test-related threat) by balancing attention allocation may be an efficient way to intervene in test anxiety (e.g., Badura-Brack et al., 2015; Bardeen et al., 2017).

5. Conclusions

The results found that the HTA group showed a dynamic attention pattern that fluctuated between vigilance and avoidance at 100 ms and

500 ms. The HTA group was more vigilant than the LTA group in the duration of 500 ms when strategic attention was concerned, proposing that the attentional vigilance in test anxiety was not an automatic process.

Declarations

All procedures were in accordance with the ethical principles of human experimentation and with the approval of the ethical committee of the Nanjing University. All participants who attended the experiments gave informed consent for participation and publication. The datasets and materials generated during and analyzed during the current study are available from the corresponding author on reasonable request.

Data Availability

Data will be made available on request.

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Contributors

Cenlou Hu developed the study concept. Cenlou Hu, Xueling Song and Renlai Zhou contributed to the study design. Testing and data collection were performed by Cenlou Hu, Jintao Song, and Yan Hong. Cenlou Hu performed the data analysis and interpretation under the supervision of Renlai Zhou. Cenlou Hu drafted the manuscript.

Role of the funding source

The funders had no role in the study design, conduct of the study; in collection, management, analysis, and interpretation of the data, or in the preparation, review, or approval of the manuscript, and decision to submit the manuscript for publication.

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