



## Test anxiety impairs inhibitory control processes in a performance evaluation threat situation: Evidence from ERP



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### ABSTRACT

Attentional Control Theory proposes that test anxiety impairs inhibitory control, and high test anxiety (HTA) individuals often allocate greater top-down attentional control resources to maintain comparable task performance compared to low test anxiety (LTA) individuals. This study examined how test anxiety impairs inhibitory control. Eighty participants were required to perform a hybrid Go/Nogo Flanker task in the performance evaluation threat or no performance evaluation threat conditions, while behavioral and EEG data were recorded. The ERP results showed that HTA participants revealed significantly larger Nogo but not incongruent related N2 amplitude than LTA participants in the threat condition. In the threat condition, HTA individuals were associated with increased recruitment of top-down attentional control resources to perform the response inhibition task but not the interference suppression task.

### 1. Introduction

Test anxiety refers to a situation specific form of anxiety, with intrusive anxiety related cognitive, behavioral, and affective characteristics elicited by testing stimuli in academic or evaluative settings (Zeidner, 1998). The cognitive element of test anxiety concerns worrisome and negative self-statements concerning failure and one's competence. A past study demonstrated that test anxiety would increase risk for subsequent anxiety or depression disorders (Leadbeater, Thompson, & Gruppuso, 2012). Individuals with high test anxiety (HTA) tend to view the performance evaluative situation as threatening stimuli. Evidence supports that test anxiety impairs the performance of cognitive tests which require attentional control resources, especially in the performance evaluation threat situation (Derakshan & Eysenck, 2009; Eysenck, Derakshan, Santos, & Calvo, 2007; Keogh & French, 2001; Von der Embse, Jester, Roy, & Post, 2018). A meta-analysis of about 238 studies showed that test anxiety was significantly and negatively related to a wide range of educational performance outcomes (Von der Embse et al., 2018).

Inhibitory control is a function that uses attentional control to override a strong internal predisposition or external lure, and instead do

what's more appropriate or needed (Diamond, 2013). The Attentional Control Theory (ACT) claims that test anxiety impairs inhibitory control (Derakshan & Eysenck, 2009; Eysenck & Derakshan, 2011; Eysenck, Derakshan, et al., 2007). Importantly, in order to offset this deficit, HTA individuals often use compensatory strategies such as recruiting greater top-down attentional control resources when completing an inhibitory control task compared to low test anxiety (LTA) individuals (Eysenck, Derakshan, et al., 2007). Thus, some studies showed that anxious individuals may show evidence of disrupted inhibitory control which is related to neural but not behavioral correlates (Berggren & Derakshan, 2013; Savostyanov et al., 2009; Sehlmeyer, Konrad, Zwitserlood, Arolt, Falkenstein, & Beste, 2010).

However, firstly, most past research in this area examined how test anxiety influenced the attentional bias. Some studies used the distraction task or dot-probe task to test how test anxiety and the performance evaluation threat influence the individual's ability to inhibit test related threat stimuli (Keogh & French, 2001; Putwain, Langdale, Woods, & Nicholson, 2011). They found that the HTA individuals had an attentional bias towards test related threat stimuli in the performance evaluation threat condition only. Huan Zhang used a modified flanker task in which emotional distractors, specifically test related threat or neutral

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words, were embedded in centrally presented hollow arrows (Zhang, Zhou, & Zou, 2015). They found that HTA individuals reported a significant reduction in efficiency of inhibitory control compared to controls when the fillers were test related threat words. In a no performance evaluation threat condition, using an emotional Stroop task and a numerical Stroop task in combination with evoked event-related potential (ERP), Zhang, De Beuckelaer, Chen, and Zhou (2019) found that HTA individuals showed inhibitory control deficits when the stimuli were test related threat words compared to LTA individuals; however, HTA individuals had no significant performance difference while performing the numerical Stroop task compared to LTA individuals. In recent years, some related studies showed that anxiety can impair inhibitory control processes even without emotional distracters (Berggren & Derakshan, 2013). We did not know whether test anxiety would impair the inhibitory control processes without emotional distracters.

Secondly, considering the inhibitory control measurement paradigms, it should be pointed out that inhibitory control is not a simple process. It may actually be composed of two component processes, often referred to as interference suppression (the ability to control for distracting stimuli or information due to stimulus competition) and response inhibition (the suppression of a prepotent or automatic behavioral response) (Friedman & Miyake, 2004).

Finally, there is still a gap in the literature on the mechanism of how test anxiety impairs inhibitory control (Berggren & Derakshan, 2013; Eysenck, Nazanin, Rita, & Calvo, 2007). ACT predicts that HTA individuals often allocate greater top-down attentional control resources than LTA individuals in order to maintain comparable task performance (Berggren & Derakshan, 2013; Eysenck, Derakshan, et al., 2007). However, one recent study also showed that it would become decreasingly possible for anxious individuals to compensate for impaired inhibitory control by allocating greater top-down attentional control resources when the available attentional control resources were limited, or the overall demands on the attentional control were increased (Wei, Beuckelaer, & Zhou, 2021). Therefore, in the present study, the hybrid inhibitory control task which can be used to measure both interference suppression and response inhibition was used (Brydges et al., 2012; Zhang et al., 2015). We examined whether HTA individuals could recruit greater top-down attentional control resources when completing an inhibitory control task compared to LTA individuals.

In addition, the related ERP components: N2 and P3 were used to measure the inhibitory control processes. The N2 is a fronto-central stimulus-locked component with a latency of between 200 and 350 ms (Folstein & Van Petten, 2007). The N2 may reflect attentional control processes used to focus attention on task-relevant aspects of a situation (Tillman & Wiens, 2011). Compared to the congruent trials, incongruent and Nogo trials both generally produce a larger N2 amplitude. Some studies found that high anxious individuals had a larger N2 amplitude while performing the inhibitory control task than low anxious individuals (Berggren & Derakshan, 2013). In other words, high anxious individuals allocated greater top-down attentional control resources than low anxious individuals. Thus, the N2 can be used to measure top-down attentional control resource allocation in studies about anxiety related emotions and inhibitory control (Dennis & Chen, 2009; Nieuwenhuis, Yeung, Wildenberg, & Ridderinkhof, 2003; Owens et al., 2015; Sehlmeyer et al., 2010).

The P3 wave is a late ERP component appearing in the parietal region from 300 to 600 ms after the stimulus. Flanker related P3 amplitude is modulated by task difficulty, and incongruent trials produce a smaller P3 amplitude compared to congruent trials (Gonzalezvillar & Carrillo-delapena, 2017; Kok, 2001). Nogo P3 is related to the later process of inhibitory control which may reflect the monitoring of the outcome of inhibition or motor inhibition (Sehlmeyer et al., 2010; Smith et al., 2008; Zordan et al., 2008), and past studies showed that Nogo P3 amplitude is modulated by cognitive self-evaluation, but not trait anxiety (Righi et al., 2009; Sehlmeyer et al., 2010).

Above all, in the present study, individuals needed to perform the

hybrid Go/Nogo Flanker task which consisted of three conditions: congruent (0.5 probability), incongruent (0.25 probability), and Nogo conditions (0.25 probability) in the performance evaluative threat or no performance evaluation threat conditions. Taking into account that test anxiety is a situation-specific form of anxiety (Zeidner, 1998), the participants in the performance evaluation threat condition were instructed that the task was related to academic ability. By using this method, the participants were expected to be stressed, especially for HTA participants (Keogh & French, 2001). Thus, we predicted that test anxiety would impair inhibitory control processes especially in the performance evaluation threat condition, as HTA individuals would recruit greater top-down attentional control resources in order to maintain comparable task performance compared to LTA individuals in the performance evaluation threat condition. More specifically, we expected that, in the performance evaluation threat condition, compared to LTA individuals, (1) behavioral: HTA individuals might have longer reaction times (RTs) for the incongruent, but not for the congruent conditions; (2) ERP: HTA individuals would reveal larger N2 amplitude for the incongruent and Nogo, but not for the congruent conditions. Besides, because flanker related P3 amplitude is modulated by task difficulty (Gonzalezvillar & Carrillo-delapena, 2017), and previous studies have shown that Nogo P3 is related to cognitive self-evaluation but not trait anxiety (Righi et al., 2009), we expected that flanker related P3 amplitude would not be modulated by both test anxiety and performance evaluation threat condition. Nogo P3 amplitude was only modulated by the performance evaluation threat condition but not test anxiety.

## 2. Method

### 2.1. Participants

Initially, 447 students took part in a mass screening using the Chinese version of test anxiety scale (TAS). In accordance with Newman (Newman, 1996), those participants scoring  $>20$  on TAS were assigned to the HTA group; while those participants scoring  $<12$  on TAS were assigned to the LTA group. Subsequently, only participants who scored high on test anxiety (32.0%) or low on test anxiety (13.6%) were chosen for further consideration. However, not all selected participants were willing to participate in the subsequent experiment after hearing that the electroencephalography (EEG) experiment requires a shampoo. And, because of the time conflict, some selected participants gave up participating experiment. Finally, 40 HTA participants and 40 LTA participants were selected. In the HTA group, 20 participants were assigned to the performance evaluation threat condition (mean age =  $20.50 \pm 1.70$  years, 16 females), and 20 participants were assigned to the no performance evaluation threat condition (mean age =  $20.85 \pm 1.98$  years, 16 females). In the LTA group, 20 participants were assigned to the performance evaluation threat condition (mean age =  $20.90 \pm 1.55$  years, 14 females), and 20 participants were assigned to the no performance evaluation threat condition (mean age =  $21.20 \pm 1.61$  years, 15 females). In the present study, the main aim was to analyze the interactions between "test anxiety" (high and low) and "performance evaluation threat" (threat and no threat) in the congruent, incongruent, or Nogo conditions. In Zhang et al. (2015)'s study, when the dependent variable is the flanker interference effect, the interaction between "test anxiety" (high and low) and "valence" (test related threat and neutral words) was significant,  $F(1,33) = 4.41$ ,  $p < .05$ ,  $\eta_p^2 = .12$ . The experimental design used in the present study was similar to Zhang et al.'s. Thus, we conducted the statistical power analysis of a two-group experimental design separately for each condition. We set the  $f = \sqrt{\frac{\eta_p^2}{1-\eta_p^2}} = .37$ ,  $\alpha = .05$ , and which in combination with a power = .8, G\*Power recommended a total sample size of 60. All participants gave their written informed consent and were informed of their right to discontinue participation at any time. The experiment procedures were approved by the Ethics Committee of the Department of Psychology in

the author's university and carried out in accordance with the approved guidelines.

## 2.2. Measures

### 2.2.1. Test Anxiety

The Chinese version of TAS was adapted by Caikang Wang, and the reliability and validity were satisfactory (Wang, 2001). The Cronbach's alpha was 0.80 in the present study ( $n = 447$ ), and the Cronbach's alpha was 0.94 for the selective 80 participants.

### 2.2.2. Hybrid Go/Nogo Flanker task

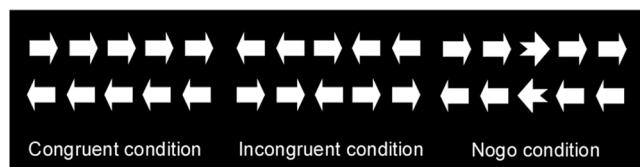
The adapted hybrid Go/Nogo Flanker task was used in this study (Brydges et al., 2012). As shown in Fig. 1, each stimulus consisted of an array of five white arrows presented on a black background, the central arrow was the target stimuli, and the other arrows were the distractor arrows. There were three conditions: (1) in the congruent condition (0.5 probability), the arrows were all facing the same direction; (2) in the incongruent condition (0.25 probability), the target arrow faced the opposite direction to the distractor arrows; (3) in the Nogo condition (0.25 probability), the arrows were all facing the same direction, but the target arrow's shape differed from the normal arrows' shape. Participants were required to respond as quickly and accurately as possible to the direction of the central normal arrow by using their left hand to press "F" if the target arrow pointed to the left, or "K" if it pointed to the right, and if the target arrow was special the participant was required to not respond. Each letter in the string subtended a visual angle of  $0.6^\circ$  vertically and  $0.8^\circ$  horizontally. The distance between the arrows was  $0.16^\circ$ . Stimuli were presented in random order for 300 ms with a 2000 ms inter-stimulus interval.

## 2.3. Design and Procedure

HTA and LTA participants were randomly allocated to the performance evaluation threat or no performance evaluation threat conditions. In the threat condition, participants were instructed that: (1) the aim of the project was to measure cognitive ability, (2) the task related to levels of intelligence and could be used to predict a degree of outcome, and (3) results would be evaluated by members of the departmental teaching staff and compared with the results of other students (Keogh & French, 2001; Putwain et al., 2011). In the no threat condition, participants were only instructed to respond as quickly and accurately as possible for each trial. After the participants had completed the study they were informed of the true nature of the study. Participants were seated comfortably about 70 cm away from a 21-in. screen, in a separate room. After a practice of 24 trials, 240 trials were presented in one block.

## 2.4. EEG Data Collection and Analysis

EEG data were collected using 66 Ag-AgCl scalp electrodes placed according to the International 10-20 system (band-pass: 0.01–100 Hz;



**Fig. 1. Stimuli of the Go/ Nogo Flanker.** The Go/ Nogo Flanker had three conditions: in the congruent condition (0.5 probability), the arrows were all facing the same direction. In the incongruent condition (0.25 probability), the target arrow faced the opposite direction to the distractor arrows. In the Nogo condition (0.25 probability), the arrows were all facing the same direction, but the target arrow's shape differed from the normal arrows' shape.

sampling rate: 500 Hz). The signals were amplified using "Neuroscan (USA)" amplifiers. Prior to recording, impedances were below 10 kOhm. During recording, the ground lead was located at AFz and the left mastoid was set as the reference.

EEG data were processed using EEGLAB (Arnaud & Scott, 2004), an open source toolbox running in the MATLAB environment. Continuous EEG data were filtered with a 30 Hz low-pass filter and a 0.1 Hz high-pass filter and were re-referenced to the average mastoids. EEG epochs were extracted using a window analysis time of 1200 ms (200 ms prestimulus and 1000 ms poststimulus) and baseline-corrected using the prestimulus interval. Furthermore, trials contaminated by eyeblinks and movements were corrected using an independent component analysis (ICA) algorithm. Only correct trials were included in the final analysis (Sehlmeyer et al., 2010; Wei et al., 2021). Finally, trials with amplitude values exceeding  $\pm 75 \mu\text{V}$  at any electrode were rejected. Consistent with previous research (Folstein & Van Petten, 2007; Pratt et al., 2011; Sehlmeyer et al., 2010), and based on visual inspection of ERP waveforms. The N2 amplitude was quantified as the negative mean amplitude at FCz between 200 and 350 ms post stimulus onset. The P3 amplitude was quantified as the positive mean amplitude at CPz between 300 and 600 ms post stimulus onset.

## 2.5. Statistical analysis

All statistical analyses were carried out in a SPSS 17.0 statistical analysis package (SPSS Inc., New York, USA). To correct the violation of the assumption of sphericity, Greenhouse-Geisser correction was applied, when necessary. Multiple comparisons were adjusted by using Bonferroni correction.

## 3. Results

### 3.1. Behavioral results

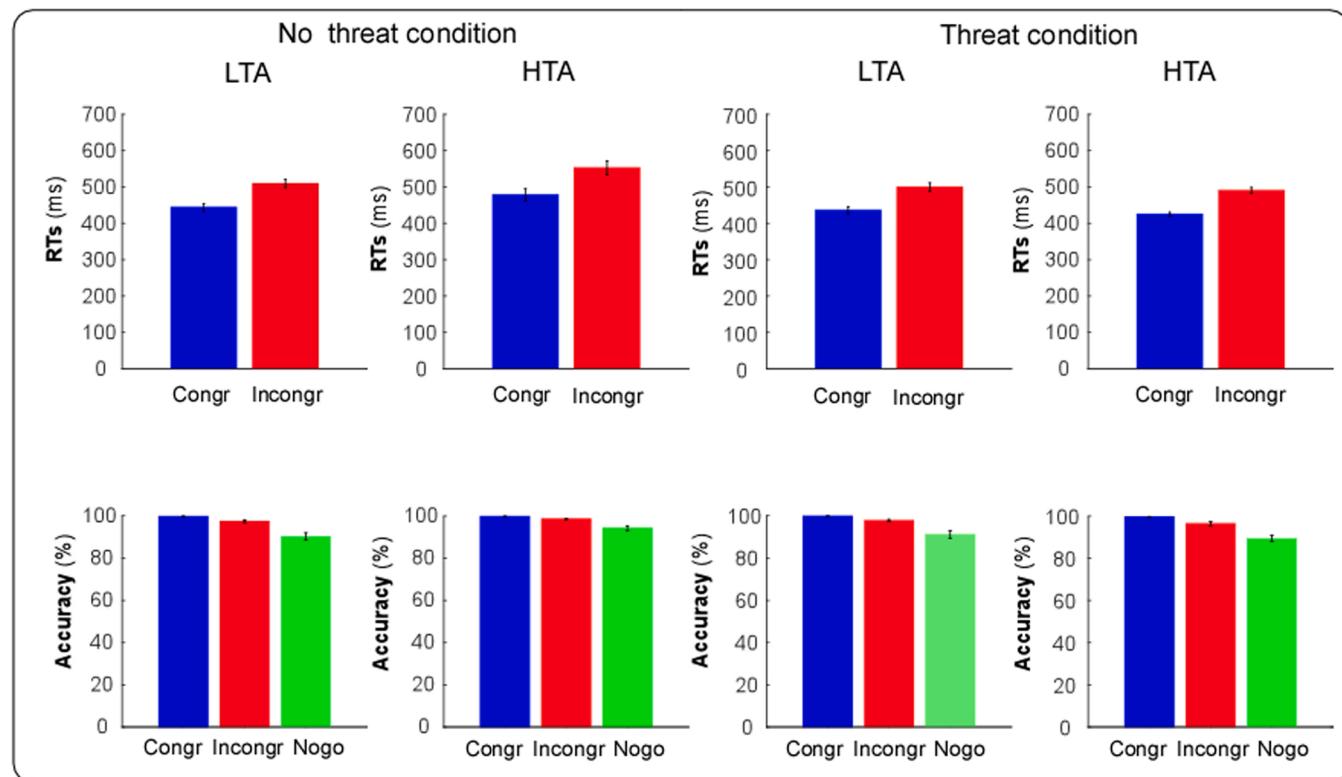
The outcomes (mean values) of RTs and accuracy are shown in Fig. 2. Only RTs for correct trials were considered. RTs exceeding 3 SD of the participants mean scores were also discarded.

#### 3.1.1. RTs

We performed the three-way mixed analyses of variance (ANOVA) on RTs with "test anxiety" (high and low) and "performance evaluation threat" (threat and no threat) as between-subject factors, with "task condition" (congruent and incongruent) as the within-subject factor. The results showed that a significant main effect was found for the task condition,  $F(1, 76) = 554.76, p < .001, \eta_p^2 = .88$ , 95% CI [61.57, 72.94], which indicated faster RTs for the congruent condition ( $445.97 \pm 5.48$  ms) than the incongruent condition ( $513.22 \pm 6.48$  ms); a significant main effect was found for the performance evaluation threat,  $F(1, 76) = 8.02, p = .005, \eta_p^2 = .10$ , 95% CI [10.18, 56.62], which indicated faster RTs in the threat condition ( $462.90 \pm 8.25$  ms) than in the no threat condition ( $496.30 \pm 8.25$  ms). The interaction between test anxiety and performance evaluation threat was significant,  $F(1, 76) = 4.41, p = .04, \eta_p^2 = .06$ . Follow-up analyses showed that, in the no threat condition, HTA participants ( $515.82 \pm 11.67$  ms) had slower RTs than LTA participants ( $476.77 \pm 11.67$  ms,  $p = .02$ , Cohen's  $d = .27$ , 95% CI [6.20, 71.89]); HTA participants had faster RTs in the threat condition ( $457.93 \pm 11.66$  ms) than those in the no threat condition ( $p = .001$ , Cohen's  $d = .39$ , 95% CI [25.04, 90.73]). No other significant effect was found.

#### 3.1.2. Accuracy

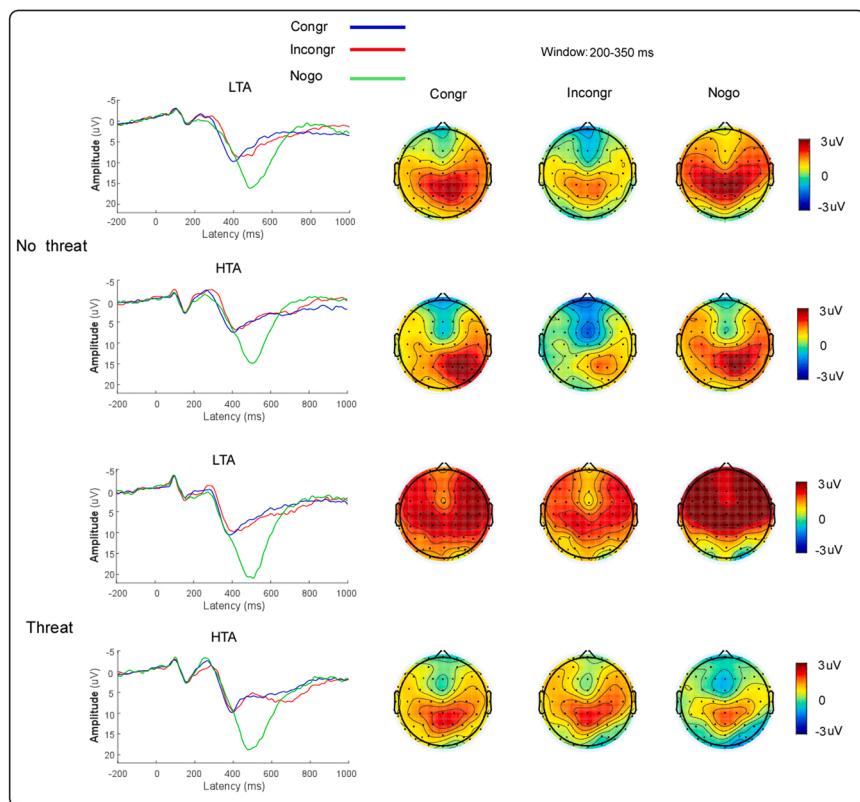
We performed the three-way mixed ANOVA on accuracy with "test anxiety" (high and low) and "performance evaluation threat" (threat and no threat) as between-subject factors, with "task condition" (congruent, incongruent and Nogo) as the within-subject factor. The results showed that, a significant main effect was found for the task



**Fig. 2.** The Mean values for reaction times (RTs) and accuracy. LTA: Low test anxiety; HTA: High test anxiety. Bars:  $\pm 1$  SEM.

condition,  $F(1.23, 93.34) = 100.83, p < .001, \eta_p^2 = .57$ . Follow-up analyses showed that participants had a lower accuracy for the incongruent condition ( $97.71\% \pm 0.29\%$ ) than the congruent condition ( $99.85\% \pm$

$0.04\%, p < .001$ , Cohen's  $d = .79$ , 95% CI [1.42%, 2.88%]), and participants had a lower accuracy for the Nogo condition ( $91.33\% \pm 0.77\%$ ) than the incongruent condition ( $p < .001$ , Cohen's  $d = 1.03$ , 95% CI



**Fig. 3.** The grand means of the ERP waveforms of the congruent, incongruent and Nogo conditions for low and high test anxiety participants averaged at electrode site FCz in the performance evaluation threat or no performance evaluation threat conditions. Additionally, the topography of the N2 is given. LTA: Low test anxiety; HTA: High test anxiety; Congr: Congruent; Incongr: Incongruent; Threat: Performance evaluation threat condition; No threat: No performance evaluation threat condition.

[4.68%, 8.07%]) and the congruent condition ( $p < .001$ , Cohen's  $d = 1.21$ , 95% CI [6.62%, 10.42%]). The interaction between test anxiety and performance evaluation threat was significant,  $F(1, 76) = 5.23$ ,  $p = .03$ ,  $\eta_p^2 = .06$ . Follow-up analyses showed that, in the no threat condition, HTA participants tended to have higher accuracy (97.65%  $\pm$  0.63%) than LTA participants (95.99%  $\pm$  0.63%,  $p = .07$ , Cohen's  $d = .21$ , 95% CI [-0.11%, 3.45%]); HTA participants had lower accuracy in the threat condition (95.17%  $\pm$  0.63%) than those in the no threat condition ( $p = .007$ , Cohen's  $d = .31$ , 95% CI [0.71%, 4.26%]). No other significant effect was found.

### 3.2. ERP results

#### 3.2.1. N2 amplitude

The grand means of the ERP waveforms and topographic scalp maps of congruent, incongruent and Nogo conditions are shown in Fig. 3.

We performed three-way mixed ANOVA on N2 amplitude with "test anxiety" (high and low) and "performance evaluation threat" (threat and no threat) as between-subject factors, with "task condition" (congruent, incongruent and Nogo) as the within-subject factor. The results showed that a significant main effect was found for the task condition,  $F(2, 152) = 8.81$ ,  $p < .001$ ,  $\eta_p^2 = .10$ , suggesting that participants revealed a significantly larger N2 amplitude for the incongruent condition ( $-0.35 \pm 0.47 \mu\text{V}$ ) than the congruent condition ( $0.22 \pm 0.48 \mu\text{V}$ ,  $p = .02$ , Cohen's  $d = .30$ , 95% CI [0.07, 1.09]) and the Nogo condition ( $0.60 \pm 0.46 \mu\text{V}$ ,  $p < .001$ , Cohen's  $d = .44$ , 95% CI [0.41, 1.41]).

The interaction between test anxiety, task condition and performance evaluation threat was significant,  $F(2, 152) = 4.50$ ,  $p = .01$ ,  $\eta_p^2 = .06$ . Specifically, in the no threat condition, there was no significant interaction between test anxiety and task condition,  $F(2, 76) = 0.06$ ,  $p = .95$ ,  $\eta_p^2 = .001$ . In the threat condition, there was significant interaction between test anxiety and task condition,  $F(2, 76) = 8.40$ ,  $p = .001$ ,  $\eta_p^2 = .18$ . Follow-up analyses showed that HTA participants ( $-0.20 \pm 0.88 \mu\text{V}$ ) did not reveal a significantly different N2 amplitude in

the congruent condition when compared to LTA participants ( $1.38 \pm 0.88 \mu\text{V}$ ,  $p = .20$ , Cohen's  $d = .20$ ); HTA participants ( $0.13 \pm 0.93 \mu\text{V}$ ) did not reveal a significantly different N2 amplitude in the incongruent condition when compared to LTA participants ( $0.77 \pm 0.93 \mu\text{V}$ ,  $p = .58$ , Cohen's  $d = .09$ ); HTA participants revealed a significantly larger Nogo N2 amplitude ( $-0.79 \pm 0.96 \mu\text{V}$ ) than LTA participants ( $2.31 \pm 0.96 \mu\text{V}$ ,  $p = .03$ , Cohen's  $d = .38$ , 95% CI [0.37, 5.83]).

#### 3.2.2. P3 amplitude

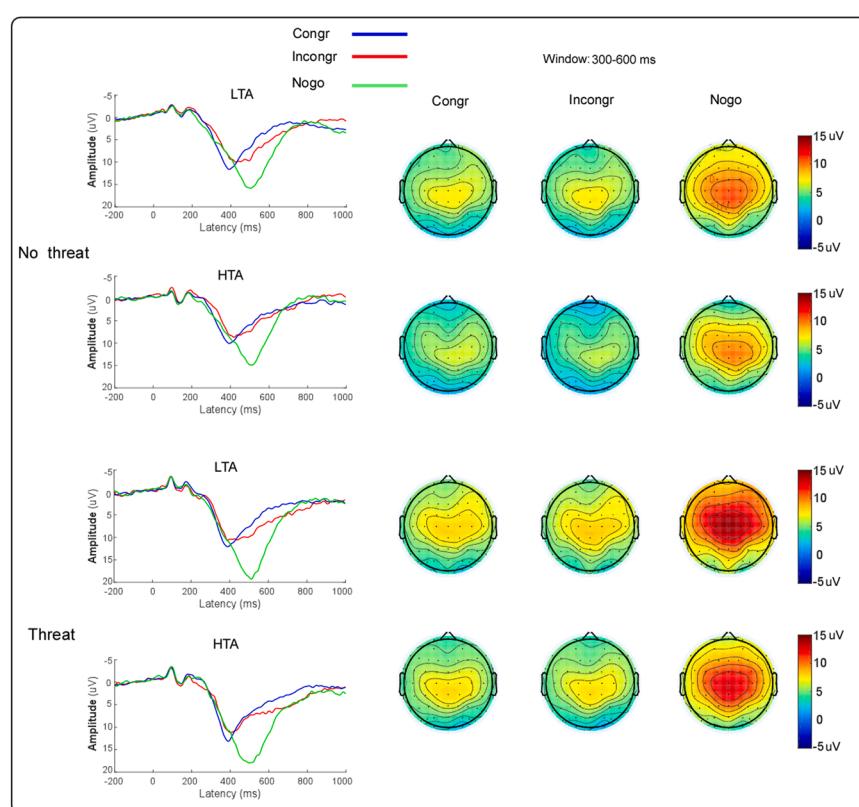
The grand means of the ERP waveforms and topographic scalp maps of congruent, incongruent and Nogo conditions are shown in Fig. 4.

Similarly, a three-way mixed ANOVA on P3 amplitude was performed. The results showed that a significant main effect was found for the task condition,  $F(1.54, 117.36) = 136.70$ ,  $p < .001$ ,  $\eta_p^2 = .64$ , suggesting that participants revealed a significantly larger P3 amplitude for the Nogo condition ( $11.72 \pm 0.56 \mu\text{V}$ ) than the congruent condition ( $7.35 \pm 0.47 \mu\text{V}$ ,  $p < .001$ , Cohen's  $d = 1.35$ , 95% CI [3.49, 5.24]) and the incongruent condition ( $7.42 \pm 0.45 \mu\text{V}$ ,  $p < .001$ , Cohen's  $d = 1.51$ , 95% CI [3.51, 5.08]). The interaction between task condition and performance evaluation threat was marginally significant,  $F(2, 152) = 2.78$ ,  $p = .065$ ,  $\eta_p^2 = .035$ . Follow-up analyses showed that participants had significantly larger Nogo P3 amplitude ( $12.94 \pm 0.79 \mu\text{V}$ ) in the threat condition than those in the no threat condition ( $10.49 \pm 0.79 \mu\text{V}$ ,  $p = .03$ , Cohen's  $d = .27$ , 95% CI [0.23, 4.67]).

## 4. Discussion

The aim of the present study was to examine how test anxiety impairs inhibitory control. To do this, we assessed behavioral performance and ERP activity while HTA and LTA individuals performed the adapted hybrid Go/Nogo Flanker task in the performance evaluation threat and no performance evaluation threat situations. Consistent with our hypothesis, in the threat condition, the ERP results showed that HTA

**Fig. 4.** The grand means of the ERP waveforms of the congruent, incongruent and Nogo conditions for low and high test anxiety participants averaged at electrode site CPz in the performance evaluation threat or no performance evaluation threat conditions. Additionally, the topography of the P3 is given. LTA: Low test anxiety; HTA: High test anxiety; Congr: Congruent; Incongr: Incongruent; Threat: Performance evaluation threat condition; No threat: No performance evaluation threat condition.



individuals had larger Nogo N2 amplitude than LTA individuals. Flanker related P3 amplitude was not modulated by both test anxiety and performance evaluation threat condition, and only Nogo P3 amplitude increased from the no threat to the threat conditions. However, contrary to our hypothesis, there was no significant difference between HTA individuals and LTA individuals for incongruent N2 amplitude. In addition, behavioral results showed that, in the no threat condition, HTA individuals had longer RTs to perform the hybrid Go/Nogo Flanker task than LTA individuals; in the threat condition, there was no significant different RTs between HTA and LTA individuals. HTA individuals had faster RTs and lower accuracy in the threat condition than those in the no threat condition, with no significant interaction effect between test anxiety and task condition.

Importantly, behavioral results showed that there was no significant interaction between test anxiety and task condition. And as many previous behavioral studies about high worriers and other anxious individuals also found no significant correlation relationship between anxiety level and RTs, the present study was consistent with previous research in showing that RTs might be not a good measurement of top-down attentional control resource allocation (Basten et al., 2011; Owens et al., 2015; Righi et al., 2009; Savostyanov et al., 2009; Sehlmeyer et al., 2010). Interestingly, the results showed that HTA individuals took longer times to perform the task than LTA individuals in the no threat condition. In the no threat condition, HTA individuals may use more conservative strategies to perform the current task in order to get a better performance. HTA individuals had faster RTs and lower accuracy in the threat condition than those in the no threat condition. The findings could potentially be related to enhanced vigilance and reduced cognitive control in no threat to threat conditions (Fan et al., 2009; Fan, McCandliss, Sommer, Raz & Posner, 2002). The other possible explanations are that the result of the speed-accuracy trade-off, or that HTA individuals (compared to LTA individuals) altered their decision style in response to a perceived performance evaluative threat. What's more, it indicated only that the HTA individuals were influenced by the performance evaluation threat. The study provides further support that test anxiety is a situation specific form of anxiety (Zeidner, 1998).

As expected, HTA individuals revealed larger Nogo N2 amplitude than LTA individuals only in the threat condition. Firstly, this supported the theory that HTA individuals would recruit greater top-down attentional control resources to perform the inhibitory control task to achieve a comparable performance (Derakshan & Eysenck, 2009; Eysenck, Derakshan, et al., 2007). Many previous studies showed enhanced neural activity in high worriers and other anxious individuals while performing the inhibitory control task in the no threat condition. Owens et al. (2015) found enhanced N2 amplitude for high trait worriers while they performed an emotional flanker task. Righi, Mecacci, and Viggiano (2009) and Sehlmeyer et al. (2010) found high trait anxiety individuals had a larger Nogo N2 amplitude than low trait anxiety individuals. Ruchow, Reuter, Hermle, Ebert, Kiefer, and Falkenstein (2007) also found enhanced Nogo N2 amplitude in patients with anxiety disorders. Basten, Stelzel, and Fiebach (2011) asked individuals to perform a Stroop task, with fMRI used to measure the neural activity. The authors found that high trait anxiety individuals showed increased dorsolateral PFC activity for incongruent relative to congruent distractor trials (Basten et al., 2011). Enhanced N2 amplitude and increased dorsolateral PFC activity indicated use of more top-down attentional control resources to perform the inhibitory control task (Basten et al., 2011; Carter & Van Veen, 2007; Kerns, Cohen, Macdonald, Cho, Stenger, & Carter, 2004; Ruchow et al., 2007). Secondly, different from non-clinical trait anxiety, worry and general anxiety disorders, test anxiety is a situation specific form of anxiety (Zeidner, 1998). Just as Keogh and French (2001) found the HTA individuals exhibited an increased susceptibility to distraction only in the performance evaluation threat situation, HTA individuals have worry, thoughts and concerns about self-evaluative aspects of failure only in the performance evaluation threat situation. Thus, in the present study, test anxiety impaired inhibitory control only

in the threat condition.

In addition, we did not find that there was a significant ERP activity difference between the HTA and LTA individuals for the incongruent condition both in the threat and no threat conditions. Thus, in the threat condition, the results showed that HTA individuals enhanced frontal ERP activity in order to perform the response inhibition task (Nogo task). HTA individuals can allocate greater top-down attentional control resources to maintain levels of task performance than LTA individuals (Berggren & Derakshan, 2013). However, when performing the interference suppression task (incongruent task), HTA individuals were unable to compensate for impaired inhibitory control by allocating greater top-down attentional control resources. The differences in neural activity between HTA individuals in response inhibition and interference suppression may be caused by the different attentional control resources demands required by the two different inhibitory control tasks (Brydges et al., 2012). The response inhibition and interference suppression consumed attentional control resources (Friedman & Miyake, 2004). Successful interference suppression required more attentional control resources than successful response inhibition (Brydges et al., 2012). Therefore, HTA individuals were able to allocate greater top-down attentional control resources to compensate for the adverse effects of anxiety on response inhibition (Righi et al., 2009; Sehlmeyer et al., 2010). However, when the available attentional control resources were inadequate and the overall demands on the attentional control were increased, HTA individuals were unable to allocate greater top-down attentional control resources to compensate for impaired interference suppression (Wei et al., 2021).

Qi et al. (2014) investigated how trait anxiety impaired the inhibitory control using a dual-task design. They found that high trait anxiety individuals had a larger N2 interference effect than the low trait anxiety individuals only in the high working memory load condition. They pointed out that HTA and LTA groups differed in their abilities to inhibit distractors when limited WM resources were consumed by the high working memory load. However, the high working memory load may consume less attentional control resources than the threat condition. Enhanced incongruent amplitude for high anxiety individuals was found in Senqing Qi's study but not in the present study. Thus, whether HTA individuals (compared to LTA individuals) can increase recruitment of top-down attentional control resources to perform the inhibitory control task, depends on both the task demands on the attentional control and the individuals' available attentional control resources. Of course, further studies need to test this assumption.

Finally, flanker related P3 amplitude is linked to task difficulty (Gonzalezvillar & Carrillo delapena, 2017; Kok, 2001). Thus, the results showed that both incongruent and congruent P3 amplitudes were not modulated by both test anxiety and the performance evaluation threat condition. Although the Nogo P3 is related to the response inhibition, the underlining mechanism is debatable (Polich, 2007; Righi et al., 2009). Nogo P3 amplitude decreased in individuals who reported a higher frequency of cognitive failures as assessed by Cognitive Failures Questionnaire (Righi et al., 2009). In the threat condition, more cognitive resources were needed, then a larger Nogo P3 amplitude was found in the threat condition. Thus, the present study supported that the Nogo P3 may reflect the monitoring of the outcome of inhibition.

Our study has some limitations as well. Firstly, most of the individuals were female. Although no studies have reported that there was an interaction effect between gender and anxiety on inhibitory control. Further studies are needed to consider gender balance. Secondly, no jitter was introduced into the inter-stimulus interval, which may have potential negative effects on the N2 and P3 amplitude measurement. This would reduce the reliability of results. Finally, the performance evaluation threat condition in the present study is not equivalent to a real evaluative setting. Future studies should examine how test anxiety impairs inhibitory control in a real evaluative setting.

In summary, the present study showed that in the performance evaluation threat condition, HTA individuals were associated with

increased recruitment of top-down attentional control resources to compensate for impaired response inhibition, as there was enhanced neural activity while performing the Nogo task. However, it would be impossible for HTA individuals to increase recruitment of top-down attentional control resources while performing the interference suppression task. Our findings extended the neural mechanism of frontal lobe in HTA individuals while performing the inhibitory control task.

## Declaration of Competing Interest

The authors report no declarations of interest.

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## References

- Arnaud, D., & Scott, M. (2004). EEGLAB: An open source toolbox for analysis of single-trial EEG dynamics including independent component analysis. *Journal of Neuroscience Methods*, 134(1), 9–21. <https://doi.org/10.1016/j.jneumeth.2003.10.009>
- Basten, U., Stelzel, C., & Fiebach, C. J. (2011). Trait anxiety modulates the neural efficiency of inhibitory control. *Journal of Cognitive Neuroscience*, 23(10), 3132–3145. [https://doi.org/10.1162/jocn\\_a\\_00003](https://doi.org/10.1162/jocn_a_00003)
- Berggren, N., & Derakshan, N. (2013). Attentional control deficits in trait anxiety: Why you see them and why you don't. *Biological Psychology*, 92(3), 440–446. <https://doi.org/10.1016/j.biopsych.2012.03.007>
- Brydges, C. R., Clunies-Ross, K., Clohessy, M., Lo, Z. L., Nguyen, A., Rousset, C., ... Fox, A. M. (2012). Dissociable components of cognitive control: An event-related potential (ERP) study of response inhibition and interference suppression. *PLoS One*, 7(3), Article e34482. <https://doi.org/10.1371/journal.pone.0034482>
- Carter, C. S., & Van Veen, V. (2007). Anterior cingulate cortex and conflict detection: An update of theory and data. *Cognitive, Affective, & Behavioral Neuroscience*, 7(4), 367–379. <https://doi.org/10.3758/CABN.7.4.367>
- Dennis, T. A., & Chen, C. C. (2009). Trait anxiety and conflict monitoring following threat: An ERP study. *Psychophysiology*, 46(1), 122–131. <https://doi.org/10.1111/j.1469-8986.2008.00758.x>
- Derakshan, N., & Eysenck, M. W. (2009). Anxiety, processing efficiency, and cognitive performance: New developments from attentional control theory. *European Psychologist*, 14(2), 168–176. <https://doi.org/10.1037/1528-3542.7.2.336>
- Diamond, A. (2013). Executive functions. *Annual Review of Psychology*, 64, 135–168. <https://doi.org/10.1146/annurev-psych-113011-143750>
- Von der Embse, N., Jester, D., Roy, D., & Post, J. (2018). Test anxiety effects, predictors, and correlates: A 30-year meta-analytic review. *Journal of Affective Disorders*, 227, 483–493. <https://doi.org/10.1016/j.jad.2017.11.048>
- Eysenck, M. W., & Derakshan, N. (2011). New perspectives in attentional control theory. *Personality and Individual Differences*, 50(7), 955–960. <https://doi.org/10.1016/j.paid.2010.08.019>
- Eysenck, M. W., Derakshan, N., Santos, R., & Calvo, M. G. (2007). Anxiety and cognitive performance: Attentional control theory. *Emotion*, 7(2), 336–353. <https://doi.org/10.3389/fnhum.2015.00269>
- Eysenck, M. W., Nazanin, D., Rita, S., & Calvo, M. G. (2007). Anxiety and cognitive performance: Attentional control theory. *Emotion*, 7(2), 336–353. <https://doi.org/10.1037/1528-3542.7.2.336>
- Fan, J., Gu, X., Guise, K. G., Liu, X., Fossella, J., Wang, H., & Posner, M. I. (2009). Testing the behavioral interaction and integration of attentional networks. *Brain and Cognition*, 70(2), 209–220. <https://doi.org/10.1016/j.bandc.2009.02.002>
- Fan, J., McCandliss, B. D., Sommer, T., Raz, A., & Posner, M. I. (2002). Testing the efficiency and independence of attentional networks. *Journal of Cognitive Neuroscience*, 14(3), 340–347. <https://doi.org/10.1162/089892902317361886>
- Folstein, J. R., & Van Petten, C. (2007). Influence of cognitive control and mismatch on the N2 component of the ERP: A review. *Psychophysiology*, 45(1), 152–170. <https://doi.org/10.1111/j.1469-8986.2007.00602.x>
- Friedman, N. P., & Miyake, A. (2004). The relations among inhibition and interference control functions: A latent-variable analysis. *Journal of Experimental Psychology: General*, 133(1), 101–135. <https://doi.org/10.1037/0096-3445.133.1.101>
- Gonzalezvillar, A. J., & Carrillo delapena, M. T. (2017). Brain electrical activity signatures during performance of the multisource interference task. *Psychophysiology*, 54(6), 874–881. <https://doi.org/10.1111/psyp.12843>
- Keogh, E., & French, C. C. (2001). Test anxiety, evaluative stress, and susceptibility to distraction from threat. *European Journal of Personality*, 15(2), 123–141. <https://doi.org/10.1002/per.400>
- Kerns, J. G., Cohen, J. D., Macdonald, A. W., Cho, R. Y., Stenger, V. A., & Carter, C. S. (2004). Anterior cingulate conflict monitoring and adjustments in control. *Science*, 303(5660), 1023–1026. <https://doi.org/10.1126/science.1089910>
- Kok, A. (2001). On the utility of P3 amplitude as a measure of processing capacity. *Psychophysiology*, 38(3), 557–577. <https://doi.org/10.1017/S0048577201990559>
- Leadbeater, B., Thompson, K., & Gruppuso, V. (2012). Co-occurring trajectories of symptoms of anxiety, depression, and oppositional defiance from adolescence to young adulthood. *Journal of Clinical Child & Adolescent Psychology*, 41(6), 719–730. <https://doi.org/10.1080/15374416.2012.694608>
- Newman, E (1996). *No more test anxiety: effective steps for taking tests and achieving better grades* (Vol. 1). Learning Skillspubs.
- Nieuwenhuis, S., Yeung, N., Wildenberg, W. V. D., & Ridderinkhof, K. R. (2003). Electrophysiological correlates of anterior cingulate function in a go/no-go task: Effects of response conflict and trial type frequency. *Cognitive Affective & Behavioral Neuroscience*, 3(1), 17–26. <https://doi.org/10.3758/cabn.3.1.17>
- Owens, M., Derakshan, N., & Richards, A. (2015). Trait susceptibility to worry modulates the effects of cognitive load on cognitive control: An ERP study. *Emotion*, 15(5), 544–549. <https://doi.org/10.1037/emo0000052>
- Polich, J. (2007). Updating P300: An integrative theory of P3a and P3b. *Clinical Neurophysiology*, 118(10), 2128–2148. <https://doi.org/10.1016/j.clinph.2007.04.019>
- Pratt, N., Willoughby, A., & Swick, D. (2011). Effects of working memory load on visual selective attention: Behavioral and electrophysiological evidence. *Frontiers in human neuroscience*, 5, 57. <https://doi.org/10.3389/fnhum.2011.00057>
- Putwain, D. W., Langdale, H. C., Woods, K. A., & Nicholson, L. J. (2011). Developing and piloting a dot-probe measure of attentional bias for test anxiety. *Learning and Individual Differences*, 21(4), 478–482. <https://doi.org/10.1016/j.lindif.2011.02.002>
- Qi, S., Zeng, Q., Luo, Y., Duan, H., Ding, C., Hu, W., & Li, H. (2014). Impact of working memory load on cognitive control in trait anxiety: An ERP study. *PLoS One*, 9(11), Article e111791. <https://doi.org/10.1371/journal.pone.0111791>
- Righi, S., Mecacci, L., & Viggiano, M. P. (2009). Anxiety, cognitive self-evaluation and performance: ERP correlates. *Journal of Anxiety Disorders*, 23(8), 1132–1138. <https://doi.org/10.1016/j.janxdis.2009.07.018>
- Ruchow, M., Reuter, K., Hermle, L., Ebert, D., Kiefer, M., & Falkenstein, M. (2007). Executive control in obsessive-compulsive disorder: Event-related potentials in a Go/Nogo task. *Journal of Neural Transmission*, 114(12), 1595–1601. <https://doi.org/10.1007/s00702-007-0779-4>
- Savostyanov, A. N., Tsai, A. C., Liou, M., Levin, E. A., Lee, J.-D., Yurganov, A. V., & Knyazev, G. G. (2009). EEG-correlates of trait anxiety in the stop-signal paradigm. *Neuroscience Letters*, 449(2), 112–116. <https://doi.org/10.1016/j.neulet.2008.10.084>
- Sehlmeyer, C., Konrad, C., Zwitserlood, P., Arrolt, V., Falkenstein, M., & Beste, C. (2010). ERP indices for response inhibition are related to anxiety-related personality traits. *Neuropsychologia*, 48(9), 2488–2495. <https://doi.org/10.1016/j.neuropsychologia.2010.04.022>
- Smith, J. L., Johnstone, S. J., & Barry, R. J. (2008). Movement-related potentials in the Go/NoGo task: The P3 reflects both cognitive and motor inhibition. *Clinical Neurophysiology*, 119(3), 704–714. <https://doi.org/10.1016/j.clinph.2007.11.042>
- Tillman, C. M., & Wiens, S. (2011). Behavioral and ERP indices of response conflict in Stroop and Flanker tasks. *Psychophysiology*, 48(10), 1405–1411. <https://doi.org/10.1111/j.1469-8986.2011.01203.x>
- Wang, C. (2001). Reliability and validity of test anxiety scale chinese version. *Chinese Mental Health Journal*, 15(2), 96–97. <https://doi.org/10.1007/s10578-007-0079-0>
- Wei, H., Beuckelaer, A. D., & Zhou, R. (2021). Enhanced or impoverished recruitment of top-down attentional control of inhibition in test anxiety. *Biological Psychology*, 161 (5), Article 108070. <https://doi.org/10.1016/j.biopsych.2021.108070>
- Zeidner, M (1998). *Test anxiety: The state of the art*. Springer Science & Business Media.
- Zhang, H., Zhou, R., & Zou, J. (2015). Modulation of executive attention by threat stimulus in test-anxious students. *Frontiers in Psychology*, 6, 1486. <https://doi.org/10.3389/fpsyg.2015.01486>
- Zhang, W., De Beuckelaer, A., Chen, L., & Zhou, R. (2019). ERP evidence for inhibitory control deficits in test-anxious individuals. *Frontiers in Psychiatry*, 10(645), 645. <https://doi.org/10.3389/fpsyg.2019.00645>
- Zordan, L., Sarlo, M., & Stablum, F. (2008). ERP components activated by the "GO!" and "WITHHOLD!" Conflict in the random sustained attention to response task. *Brain and Cognition*, 66(1), 57–64. <https://doi.org/10.1016/j.bandc.2007.05.005>