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Deficits of proactive control in individuals with test anxiety: Evidence from ERPs

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ABSTRACT

Proactive control in cognitive control is characterized by an individual's ability to maintain representations of goal-relevant information prior to responding to prevent conflicts. Text anxiety is a situation-specific personality trait characterized by excessive fear and worry about exams, accompanied by emotional issues. Individuals with high test anxiety exhibit deficiencies in cognitive control capabilities, but whether there is a defect in proactive control remains unclear. In this study, ERP technology was used to record the brain electrical activity of participants with high and low test anxiety during the performance of the AX-CPT task, and the difference in proactive control ability between the two groups of participants was examined. Behaviorally, individuals with high test anxiety(HTA) exhibited significantly lower accuracy rates in all three conditions compared to those with low test anxiety, and also showed a lower d' Context index. In terms of neural indicators, participants with HTA showed a significantly lower CNV component in the BX pairs than those with low test anxiety, HTA individuals lack the ability to actively maintain cues. Additionally, higher amplitudes of the N2 and P3 were generated in the AY and BX pairs, high test anxiety individuals require more cognitive resources to inhibit cognitive conflict. Results suggests that individuals with HTA exhibit deficiencies in proactive control abilities. This study explores the relationship between such deficits and test anxiety.

1. Introduction

Examinations have consistently been the most widely used selection method globally and are also an important life events individuals face from a early childhood. The results of examinations have an important impact on personal life, particularly in academic and career prospects. In this context, examinations have evidently become a significant source of stress that modern society imposes on individuals. However, not everyone is adept at coping with the immense pressure brought by exams. A portion of people, in particular, become excessively concerned about their potential poor performance and the fear of failure, involuntarily exhibiting heightened levels of anxiety (Hill & Wigfield, 1984; Lotz & Sparfeldt, 2017; Zeidner, 1998). This form of anxiety is termed test anxiety (TA), which is closely related to examinations and accompanies them(Lotz & Sparfeldt, 2017). Test anxiety is closely associated with examinations and emerges or intensifies as the exams approach. It is a situation-specific personality trait, characterized by anxiety-related cognitive, behavioral, and emotional responses triggered by exam-related stimuli, particularly in educational or evaluative contexts (Zeidner, 1998; Zeidner, 2007). Individuals with high test anxiety tend to regard evaluative situations as threatening stimuli, showing excessive fear and worry about the test, accompanied by emotional problems (Szafranski et al., 2012). Concurrently, this heightened worry about exams negatively impacts their normal performance during the tests. Studies have shown that test anxiety significantly impairs individuals' cognitive abilities, with several theories explaining the impact of test anxiety on cognitive function (Hembree, 1988; Karatas, 2013; Nathaniel et al., 2017; Zeidner, 1998; Zamani & Pouratashi, 2018). For instance, the cognitive attention theory suggests that individuals with test anxiety excessively ruminate over test and the various situations encountered during the process, continuously depleting their limited attentional resources, which in turn leads to impaired inhibitory control abilities (Eysenck & Byrne, 1992; Eysenck & Derakshan, 2011; Eysenck et al., 2007; Nazanin & Eysenck, 2009).

Cognitive control can ensure that individuals are goal-oriented and adjust their cognitive, behavioral, emotional, and motivational

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processes (Cocchi et al., 2013; Diamond, 2013; Zink et al., 2021). According to different functional roles, Diamond(2013) subdivides cognitive control into several interrelated but distinct core subcomponents: inhibitory control, working memory, and cognitive flexibility. In the current research on the inhibitory abilities of test anxiety, many researchers take inhibition control as the theoretical basis. The experimental paradigm used to assess individual inhibitory control ability greater emphasis on detection and resolution after the occurrence of stimuli, with attentional resources serving as the foundation for behavioral responses. (Berggren & Derakshan, 2013; Pacheco-Unguetti et al., 2010; Wei et al., 2021). However, previous studies have some limitations. In recent years, some researchers have argued that traditional inhibition control theory greater emphasis on an individual's ability to inhibit their behavior when faced with interference or dominant responses, without highlighting the individual's initiative during the process of inhibiting behavior (Braver et al., 2007). Research has shown that attentional control involves both the capacity for top-down, proactive suppression, interruption, or delay of actions (Brydges et al., 2012; DeWall et al., 2011; Diamond, 2013) and goal-oriented behaviors that are consciously detected and monitored (Petersen & Posner, 2012), which can be divided into two systems: top-down and bottom-up. The top-down cognitive control system is goal-driven, while the bottom-up cognitive control system is stimulus-driven. On this basis, Braver proposed the Dual Mechanisms of Cognitive Control Account (DMC) theory, which posits that individuals have two distinct modes of cognitive control: proactive control and reactive control. Proactive control can be understood as a form of "early selection", by selectively processing task-relevant cueing information with attention and actively maintaining it during the pre-task phase to shape response preparation accordingly. It is a cue-driven control, which is mainly influenced by top-down processing (Braver, 2012). In contrast, reactive control involves avoiding incorrect responses and serves as a "correction mechanism". Based on the aforementioned theoretical framework, we found an interesting aspect of test anxiety: compared to the sudden events that induce other forms of anxiety, test as significant selection and evaluation tools, to uphold their fairness, inform participants of their timing and format well in advance. This allows individuals sufficient time to proactively manage (control) the onset of test anxiety, so as to reduce the negative impact brought by anxiety. However, this is not the case in reality, and therefore the present study was interested in whether individuals had test anxiety due to the presence of proactive control deficits.

The cue-probe AX continuum performance task (AX-CPT) effectively differentiates proactive control and reactive control (Cohen et al., 1999). This paradigm consists of cue and probe, with a blank screen interposed between them as a temporal delay. A cue stimulus (A or B) was first presented in the center of the screen after task onset, followed by a delayed blank screen, and finally a probe stimulus (X or Y). Participants were asked to respond with a key press when presented with probe X following cue A (an AX pair), while ignoring other (i.e., AY, BX, and BY pairs). The AX pairs occurred more frequently than the other three (e.g., AX accounted for 58 %, with the remaining three each at 14 %). This stimulus ratio significantly elevates the frequency of the AX pairs relative to other pairs, fostering a stronger target-response tendency towards stimuli A and X in participants. In the AY and BX pairs, this target-response tendency conflicts with the non-target responses that participants are expected to produce. For the AY pairs, strengthening reactive control enables individuals to enhance processing of the immediately following probe Y, thereby reducing the target-response tendency elicited by cue A (more ratios AX pairs would predispose individuals to respond incorrectly after the appearance of A rather than the response corresponding to AY). So AY pair reflects the individual's reactive control ability. For the BX pairs, individuals favor proactive control, which allows them to prevent conflict by actively maintaining the representation of cue B before the presentation of probe X that triggers the target response tendency. If it's a weaker cue-maintaining ability, X intensifies the false reaction (caused by more ratios AX pairs) induced by the target-response tendency. Consequently, proactive control manifests as a reduction in reaction time or error rate for BX; reactive control manifests as a reduction in reaction time or error rate for AY (Braver, 2012; Gonthier et al., 2018; Pilar et al., 2015). Additionally, the d' Context indices is a computational metric within signal detection theory. It serves to assess an individual's sensitivity, determined by both the hit rate and the false alarm rate. When a participant demonstrates heightened sensitivity, their hit rate increases while the false alarm rate decreases, indicating high discriminability. When the hit rate and false alarm rate are close in value, the participant's discriminability is moderate. Conversely, when the hit rate is low and the false alarm rate is high, the participant's discriminability is low. So, d' Context indices can be used to analyze the sensitivity of participants to cue information, with d' = Z(rate of hits to AX pairs) − Z(rate of false alarms to BX) representing sensitivity to the cue. A larger d' value indicates greater sensitivity to the cue and better proactive control (Braver, 2012).

Electrophysiological studies can effectively compensate for the limitations of behavioral indicators. Contingent Negative Variation (CNV) was first discovered by Walt and Cooper using a reaction time measurement paradigm (Walter et al., 1964). Research revealed that CNV is a negative amplitudes associated with motor preparation that emerges in response to the "cue stimulus", and this brain activity is believed to be influenced by motivation and effort levels (Zhang et al., 2017). This component reflects the degree of conscious or unconscious proactive preparation in cognitive activities. Studies have shown that the use of proactive control strategies is associated with sustained brain activation during the interval between cue-probe presentation. In the AX-CPT task, the CNV in the medial frontal regions during the cue-locked is related to anticipatory attention (Brunia, 1999) or response preparation processes (Karayanidis & Jamadar, 2014). Researchers hypothesize that the amplitude of the CNV may reflect neuronal activation during the accumulation of temporal scales, with increased allocation of attentional resources leading to greater neuronal activation intensity and higher amplitude (Macar et al., 1999). When individuals exhibit a higher amplitude CNV in response to a specific cue, it indicates that they are more proactive preparation for subsequent reactions (Shen et al., 2018; Smith et al., 2006). Previous studies have shown that individuals with high anxiety exhibit smaller amplitude CNV compared to those with low anxiety. This suggests that people with high anxiety have relatively lower proactive control abilities(Knott & Irwin, 1968; Xu et al., 2020).

When individuals need to exert cognitive control over stimuli, a negative deflection component N2 appears in the frontal-midline region of the brain within 200–300ms after stimulus onset. N2 is considered a cognitive component produced when the anterior cingulate cortex (ACC) is activated. In the dual mechanism of control theory, the ACC plays a dual role in proactive and reactive control (Braver et al., 2007). This component is typically regarded as an electroencephalographic indicator of inhibitory control or conflict monitoring abilities (Hämmerer et al., 2010; Lo, 2018; Van Veen & Carter, 2002), reflecting the individual's top-down monitoring of conflict and effort in completing inhibitory control tasks (Nieuwenhuis et al., 2003; Pires et al., 2014). Generally, the amplitude of the N2 decreases with the increase in individual conflict monitoring efficiency (Lo, 2018). Previous studies have shown that the amplitude of the N2 is significantly higher in individuals with high anxiety compared to those with low anxiety. This suggests that individuals with high anxiety require more attentional control resources than those with low anxiety when performing cognitive control tasks(Righi et al., 2009; Sehlmeyer et al., 2010). As the cognitive process continues, a positive deflection wave P3 appears in the central cortical region between 300 and 500ms after the stimulus onset, reflecting the individual's response inhibition abilityIt and conflict resolution(Bruin & Wijers, 2002; Morales et al., 2015; Pfefferbaum, Ford, Weller, & Kopell, 1985; Xu et al., 2020). It was reported that individuals with anxiety disorders exhibit higher P3 amplitudes compared to control groups, which is interpreted as an increased cost of response inhibition (Bruder et al., 2002).

Although no research has been conducted on the proactive control abilities of HTA individuals yet, substantial evidence has already been amassed regarding the proactive control abilities of trait anxiety individuals. Fales et al. (2008) used the N-back paradigm to study the activation characteristics of individuals with trait anxiety in the prefrontal cortex and found that high trait anxiety individuals exhibited more transient activation and less sustained activation in the right ventrolateral PFC under high conflict conditions, and stronger activation when re-retrieving stimulus information. This result suggests a preference for reactive control among individuals with high anxiety. Concurrently, the study also found that individuals with low anxiety exhibit similar cognitive control patterns to those with high anxiety after viewing negative clips. The inclination of anxious individuals towards reactive control may be due to heightened arousal, increased vigilance towards the environment, and enhanced attention to unexpected stimuli. Research indicates that trait anxiety can influence the balance between these two attention systems, with individuals high in trait anxiety preferentially selecting the bottom-up attention system to suppress interference information (Corbetta & Shulman, 2002). Trait anxiety enhances the impact on the stimulus-driven attentional system. When there are significant interfering stimuli or threat-related information in the environmental representation, anxious individuals are more likely to suppress interfering information through bottom-up cognitive control. These findings suggest that individuals with high trait anxiety have deficits in proactive control.

Based on the above findings, we hypothesize that individuals with high test anxiety may exhibit deficiencies in proactive control. Therefore, this study examines this hypothesis by comparing the behavioral responses and neural activities of individuals with high and low test anxiety while performing the AX-CPT task. We expected that individuals with high test anxiety may reveal more defects in proactive control strategies and weaker cue maintenance patterns during the task, manifesting in lower accuracy rates and *d*' Context indices in the AX and BX pairs at the behavioral level. At the neurophysiological level, we expect that individuals with high test anxiety will show smaller CNV amplitudes in the BX pairs and exhibit higher N2 and P3 amplitudes in the AY and BX pairs compared to those with low test anxiety. (Bruder et al., 2002; Hämmerer et al., 2010; Lo, 2018; Righi et al., 2009; Sehlmeyer et al., 2010).

2. Method

2.1. Participants

The desired sample size was calculated by performing a G*Power analysis. With $f = 0.25$, $\alpha = 0.05$, and $power = 0.8$, we obtained a recommended sample size of 44 participants (Faul et al., 2007). Participants were recruited online, exclusively from full-time university students. The screening tools used in this study included the Test Anxiety Scale (TAS), Beck Anxiety Inventory (BAI), and Beck Depression Inventory (BDI), to ensure that participants were not in a state of anxiety or depression. During the recruitment period, 188 participants completed the scales. Previous studies shown, if an individual's TAS score is below 12, it can be judged that they have a low test anxiety; if the score is above 20, it can be judged that they have a high test anxiety. Due to its definition and categorization of test anxiety levels, it is particularly suitable for selecting individuals with high test anxiety and has been widely used in relevant research(Newman, 1996). According to this criteria, 32 individuals with high test anxiety and 30 with low test anxiety were selected. Due to data quality issues, the data of 4 high test anxiety (HTA) participants and 2 low test anxiety (LTA) participants were excluded. A total of 56 participants participated in the experiment, including 28 individuals with high test anxiety (average age 19.73 ± 1.2, 14 females) and 28 with low test anxiety (average age 20.75 ± 1.65, 18 females). All selected participants were right-handed and excluded those with a history of mental illness. All participants voluntarily participated in the experiment, fully understood the possible effects before the experiment, were informed of their right to withdraw at any time, and signed the <Participants Informed Consent Form> . Participants will receive corresponding compensation after the experiment. The experimental procedures were approved by the Ethics Committee of the Department of Psychology, Nanjing University, and they were performed in accordance with approved guidelines (NJUPSY202304007).

2.2. Task and procedure

The experimental task in this study was the modified AX-CPT task. In the original paradigm, participants only responded to the AX pair and did not respond to the other pairs. The behavioral indicators reflecting the inhibitory control function of individual behavior in this paradigm depend too much on the accuracy rate, and it is difficult to exclude the interference of motion-related factors when extracting the inhibition related neural activity indicators. Therefore, by responding with both hands, not only can the reaction time indicators be obtained, but also the motor factors can be balanced as much as possible in the acquisition of neural indicators. Modified AX-CPT taskconsisting of four blocks, each containing 100 trials. Each trial is composed of a cue and a probe. In this task, cue A was a blue square; probe X was a yellow square; cue B was a green or red square; and probe Y was a green or purple square. These color squares together form four combinations: AX (blue-yellow), AY (blue-purple), BX (green-yellow), and BY (red-green). The AX combination accounted for 58 % (232 trials) of all trials, while AY, BX, and BY each accounted for 14 % (56 trials) of the total. The BX pair is employed to assess the participant's proactive control ability, while the AY pair is utilized to evaluate the participant's reactive control ability. Participants were asked to press the F key using their left index finger when the AX combination appeared on the screen. For the other three combinations the J key was pressed with the right index finger. The detailed process is shown in Fig. 1. At the beginning of the experiment, a central "+ " (3 mm×3 mm) with a duration of 1000–1500ms was presented in the center of the screen, followed by a 300 ms cue (80 mm×80 mm), and then a 600 ms blank screen. After the end of the blank screen,a "+ " (3 mm × 3 mm) will be presented at the center of the screen for a duration of 1000–1500ms. Subsequently, the stimulus was presented in the center of the screen for 300 ms (80 mm×80 mm), and there was a blank screen for 600 ms at the end. The duration of one trial ranged from 3800 to 4800 ms (Rico-Picó et al., 2021).

Participants completed the experiment within an electromagnetic shielding room. All were informed of the requirement to perform the task both effectively and swiftly. Prior to the formal experiment, participants underwent 20 practice trials to familiarize themselves with the experimental procedures.

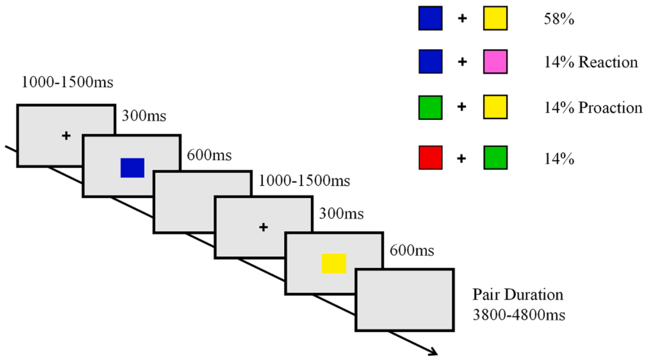

Fig. 1. Graphical representation of AX pair of the AX–CPT protocol and the cue-probe combinations. (Color).

2.3. EEG record and analysis

Eeg data were recorded using a Neuroscan 64-channel portable amplifier, with 64 Ag/AgCI electrodes arranged according to the 10–20 system on the electrode cap. During the recording process, the reference electrode was placed on the left mastoid, and the forehead was grounded. The sampling rate was 1000 Hz, with a filter bandwidth of 0.05–100 Hz. There are two EOG electrodes in total. An electrodes were placed laterally to the eyes for horizontal eye movement (HEOG) recording and the other was placed above and below the left eye to record vertical eye movements (VEOG). The input impedance of all recording electrodes was below 20 kΩ. The processing of EEG data was conducted using the EEGLAB2019 toolkit on the MATLAB2019b platform. During the analysis, the reference was switched from unilateral mastoid to average reference across the entire brain, followed by bandpass filtering of the EEG data (0.1–40 Hz). Bad channels were identified visually and replaced with spherical interpolation, with no more than 5 % of channels interpolated per participant. Data were segmented into cue and probe phases, with a time window of 2400 ms for the cue-locked and 1500 ms for the probe-locked. The baseline for both phases was set to the 200 ms pre-stimulus period. To remove artifacts, trials with significant drift were manually excluded first, followed by the use of Independent Component Analysis (ICA) to identify and remove artifacts related to eye movements and muscle activity in the EEG data.Among all participants, 3 ± 3 ICA components identified as artifacts through visual inspection were excluded. Additionally, segments with amplitudes exceeding ± 100μV at any electrode were removed. To further ensure the rigor of the results, only ERPs that made correct judgments about the task were calculated. Consequently, the results of 4 individuals with high test anxiety and 2 with low test anxiety were excluded. Finally, there were no differences in the number of epochs retained across different pairs ($ps > 0.05$).

Based on previous studies, we selected different EEG components and their corresponding analysis channels. We selected Cz as the channel for analyzing CNV, using the average amplitude of EEG within the time window of 1500–2300ms post-cue as the measure of CNV (Hämmerer et al., 2010). For the analysis of the N2 component following a stimulus, we selected Fz and FCz as the channels, with the time window set at 200–300ms post-stimulus. Lastly, for the analysis of the P3 component post-stimulus, Cz and Pz were chosen as the channels, utilizing the time window of 350–650ms (Rico-Picó et al., 2021; Wessel, 2018). To enhance the signal-to-noise ratio and eliminate the instability caused by component peaks and latencies under different conditions, we selected the average amplitude within 50 ms before and after the N2 peak under different conditions as N2 for analysis, and the average amplitude within 150 ms before and after the P3 peak under different conditions as P3 for analysis (Clayson et al., 2013).

2.4. Statistical analysis

Data was analyzed using SPSS 21. Independent sample T-tests were conducted to calculate the significance of age differences between the two groups of participants ($p > 0.05$). The accuracy, average reaction time for correct trials, *d*' Context index, and amplitude of ERPs were calculated for each condition in the participants. For RT, accuracy measures, repeated measures analysis of variance (ANOVA) was employed with Condition (AX, AY, and BX)as within-subject variables, and Group (HTA, LTA) as a between-subject variable. For ERPs measures, repeated measures ANOVA was employed with Condition (AX, AY, and BX) and Electrode (Fz and FCz; Cz and Pz) as a within subject variable, and Group (HTA, LTA) as the between-subject variable. Simple effects were used for further analysis when the main effect interaction was significant. All pairwise comparisons were corrected by Bonferroni correction. Finally, Pearson's correlation was used to explore the relationship between behavioral and ERPs measures. Alpha level of significance was set as $p < .05$.

In addition, we also used pooled electrodes to verify the results, but there were differences in amplitude between different electrodes with the same composition. Therefore, pooled electrodes could not accurately reflect the experimental results, so single electrode was used for statistical analysis in this study.

3. Results

3.1. Behavioral results

Means and SD of RT and accuracy under each condition are presented in Table 1.

To eliminate the possibility of too fast responses due to anticipation, trials with reaction times below 200 ms were excluded before calculating the average reaction time for correct trials. For RT, ANOVA revealed a main effect of condition, [$F(2, 108) = 150.56$, $p < 0.001$, $\eta_p^2 = 0.736$]. Pairwise comparisons revealed that response times in the AY were significantly longer in both groups compared to the other two conditions, ($Fs \geq 49.44$, $ps < 0.001$, $\eta_p^2 \geq 0.651$). Other effects were not significant ($Fs \leq 2.62$, $ps \geq 0.08$)(see Fig. 2).

For accuracy, ANOVA revealed a main effect of condition, [$F(2, 108) = 16.18$, $p < 0.001$, $\eta_p^2 = 0.231$]. Pairwise comparisons revealed that accuracy in the AX was significantly greater than in the AY and BX conditions in the HTA group. And a main effect of group, [$F(1, 54) = 23.14$, $p < 0.001$, $\eta_p^2 = 0.3$]. There was a significant Group×Condition interaction, [$F(2, 108) = 5.25$, $p = 0.007$, $\eta_p^2 = 0.089$], simple effect analysis revealed that in the three conditions, the HTA group had a significantly lower accuracy rate compared to the LTA group, [$Fs(1, 54) = 25.15$, $p \leq 0.001$, $\eta_p^2 \geq 0.191$].

The *d'* Context index (i.e. rate of hits to AX pairs - rate of false alarms to BX pairs) showed that HTA group *d'* Context values lower than LTA group, $T(54) = 5.40$, $p < 0.001$. (see Fig. 3).

3.2. ERPs results

Means and SD of amplitudes for the different ERP components and task conditions are presented in Table 2.

3.2.1. Cue-locked CNV

Fig. 4 presents the grand average waveforms, mean amplitudes, and topographic distribution of cue-locked negative elicited by the cues for the different groups over the 1500–2300 ms time window. For cue-locked CNV, ANOVA revealed a main effect of condition, [$F(2, 108) = 13.37$, $p < 0.001$, $\eta_p^2 = 0.198$], and Group×Condition, [$F(2, 108) = 3.47$, $p = 0.035$, $\eta_p^2 = 0.06$]. Simple effect analysis revealed that in BX pairs, the average amplitude of CNV in the HTA group was significantly smaller than in the LTA group, [$F(1, 54) = 6.53$, $p = 0.013$, $\eta_p^2 = 0.108$]. Pairwise comparisons revealed that in LTA group the CNV in the BX pair is significantly higher than that under the AX and AY pairs, [$F(2, 53) = 10.16$, $p < 0.001$, $\eta_p^2 = 0.277$]. Other effects were not significant ($ps > 0.05$)(see Fig. 4).

3.2.2. Probe-locked ERPs

Fig. 5 presents the grand average waveforms, mean amplitudes, and topographic distribution of probe-locked negativity elicited by the probes for the different groups over the 200–300 ms time window.

As for the N2 amplitude, we conducted a repeated measures ANOVA including electrode (Fz and FCz) and condition (AX, AY, and BX) as within factors, and group as between-subject factor. This ANOVA revealed a significant main effect of condition, [$F(2, 108) = 5.22$, $p = 0.007$, $\eta_p^2 = 0.088$]. Pairwise comparisons revealed reduced N2 amplitude for AX in comparison to BX ($p = 0.07$) and AY ($p = 0.018$). The main effect of electrode was also significant, [$F(1, 54) = 38.71$, $p < 0.001$, $\eta_p^2 = 0.418$], indicating greater N2 amplitude for Fz ($p < 0.001$). The main effect of group was not significant ($p > 0.05$). There was a significant Group×Condition interaction, [$F(2, 108) = 5.25$,

Table 1
The means and SD of correct rate and RT for each experimental condition.

	RT			Accuracy			
	AX	AY	BX	AX	AY	BX	d'
High	404.56 (102.68)	514.13 (95.13)	402.08 (124.22)	95.5 (2.67)	86.7 (12.1)	88.6 (10.2)	84.1 (10.8)
Low	405.23 (124.65)	484.61 (109.45)	389.38 (143.73)	98.5 (1.55)	98.5 (4.8)	97.4 (3.0)	95.9 (3.7)

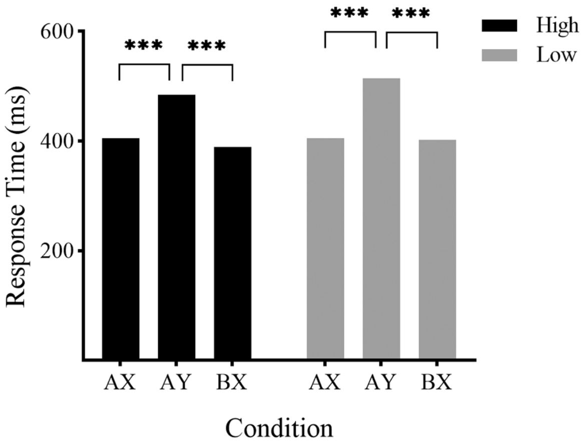

Fig. 2. Bar chart is constructed from the average reaction times of two groups of participants in three conditions. Response times in the AY were significantly longer in both groups compared to the other two conditions. * **$P < 0.001$. High : High Test Anxiety ; Low : Low Test Anxiety.

$p = 0.007$, $\eta_p^2 = 0.089$], but Group×Condition×Electrode interaction was not significant ($p > 0.05$). To further analyse the Condition×Group interaction, we conducted a separated ANOVAs including group and condition as factors for each electrode. At Fz, the condition main effect [$F(2, 108) = 5.38$, $p = 0.006$, $\eta_p^2 = 0.091$] and Condition×Group interaction were significant [$F(2, 108) = 6.62$, $p = 0.002$, $\eta_p^2 = 0.109$], but not the group main effect ($p > 0.05$). Simple effect analysis revealed that the LTA group higher N2 amplitude in AY pairs compared to AX and BX [$F(2, 53) = 4.78$, $p \leq 0.044$, $\eta_p^2 = 0.153$]. And HTA group higher in BX pairs compared to AX [$F(2, 53) = 8.45$, $p < 0.001$, $\eta_p^2 = 0.242$], with no differences between BX and AY. At FCz, the condition main effect [$F(2, 108) = 4.38$, $p = 0.015$, $\eta_p^2 = 0.075$] and Condition×Group interaction were significant [$F(2, 108) = 6.31$, $p = 0.003$, $\eta_p^2 = 0.105$], but not the group main effect ($p > 0.05$). Simple effect analysis revealed that the LTA group higher N2 amplitude in AY pairs compared to AX [$F(2, 53) = 4.54$, $p = 0.012$, $\eta_p^2 = 0.146$]. And HTA group higher in BX pairs compared to AX [$F(2, 53) = 6.37$, $p = 0.003$, $\eta_p^2 = 0.194$], with no differences between BX and AY. (see Fig. 5)

As for the P3 amplitude, we conducted a repeated measures ANOVA including electrode (Cz and Pz) and condition (AX, AY, and BX) as within factors, and group as between-subject factor. This ANOVA revealed a significant main effect of condition, [$F(2, 108) = 18.86$, $p < 0.001$, $\eta_p^2 = 0.259$]. Pairwise comparisons revealed higher P3 amplitude for AY in comparison to AX and BX ($ps < 0.001$). The main effect of electrode was also significant, [$F(1, 54) = 25.93$, $p < 0.001$, $\eta_p^2 = 0.324$], indicating greater P3 amplitude for Cz ($p < 0.001$). The main effect of group was not significant ($p > 0.05$). There was a significant Electrode×Condition interaction, [$F(2, 108) = 6.89$, $p = 0.002$, $\eta_p^2 = 0.113$], and Group×Condition×Electrode interaction was also significant [$F(2, 108) = 3.53$, $p = 0.033$, $\eta_p^2 = 0.061$]. To further analyse the Condition×Group interaction, we conducted a separated ANOVAs including group and condition as factors for each electrode. At Cz, the condition main effect [$F(2, 108) = 10.67$, $p < 0.001$, $\eta_p^2 = 0.165$], but not Condition×Group interaction and group main effect ($ps > 0.05$). Pairwise comparisons revealed that HTA group P3 amplitude was significantly greater in the AY than BX pairs[$F(2, 108) = 9.73$, $p < 0.001$, $\eta_p^2 = 0.269$], with no differences between AY and AX ($p = 0.074$). At Pz, the condition main effect [$F(2, 108) = 18.43$, $p < 0.001$, $\eta_p^2 = 0.254$] and Condition×Group interaction were significant [$F(2, 108) = 6.31$, $p = 0.003$, $\eta_p^2 = 0.105$]. Other effects were not significant ($ps > 0.05$). Pairwise comparisons revealed that LTA group P3 amplitude was significantly greater in the AY pairs than AX($p < 0.001$) and BX($p = 0.004$). And HTA group P3 amplitude was significantly greater in the AY pairs than AX [$F(2, 108) = 7.19$, $p = 0.002$, $\eta_p^2 = 0.213$], with no differences between AY and BX ($p = 0.404$). (see Fig. 6)

3.3. *Correlation analyses*

CNV in the BX pairs was used as a indicator of individual proactive preparation for subsequent responses, and we calculated the correlation between it and other behaviors and ERP indicators. CNVBX was negatively correlated with correct rate of BX ($r = -0.379$, $p = 0.004$) and d' Context index ($r = -0.324$, $p = 0.015$), and positively correlated with CNVAX amplitude ($r = 0.541$, $p < 0.001$). There was no significant correlation with other behaviors and ERP indicators ($ps > 0.11$).

4. Discussion

This study explores whether individuals with HTA exhibit deficiencies in proactive control abilities by analyzing the differences in behavior and EEG signals between participants with HTA and LTA in the AX-CPT paradigm. The results reveal that, compared to those with, HTA do indeed show deficits in proactive control. The HTA group had lower accuracy rates across all three conditions than the LTA group, and significantly smaller CNV amplitudes during the cue-locked in conditions reflecting individual proactive control compared to the LTA group. During the probe-locked, both groups of participants under the proactive control condition exhibited different amplitudes of N2 and P3. Research indicates that, compared to the LTA group, the HTA group has a significant deficiency in proactive control.

Behavioral data indicated that the HTA group exhibited lower accuracy rates than the LTA group across all three experimental conditions. In RTs index, both groups showed significantly longer RTs under the AY pairs compared to the other two conditions. Additionally, the HTA group demonstrated a lower d′ Context index, which is associated with their lack of proactive cognitive strategies during the experiment (Redick, 2014; Richmond et al., 2015).The results show that the HTA group exhibited less efficient cue processing ability under all conditions, so that lower accuracy rates when stimuli were presented (Braver, 2012).

Research has shown that individuals' more proactive control and preparation for the BX pairs lead to reduced accuracy when AY (Burgess & Braver, 2010). However, our results indicate that the LTA group still performed better on AY than the HTA group. This is consistent with the findings of previous studies (Burgess et al., 2011), suggesting that despite adopting more proactive control strategies, individuals with LTA can still effectively engage in reactive control.

CNV represents an individual's anticipatory attention (Brunia, 1999) or response preparation process (Karayanidis & Jamadar, 2014). This study found that the CNV amplitude in the HTA group under the BX pairs was significantly smaller than that in the LTA group, with no significant differences in CNV amplitudes under the other two conditions. This

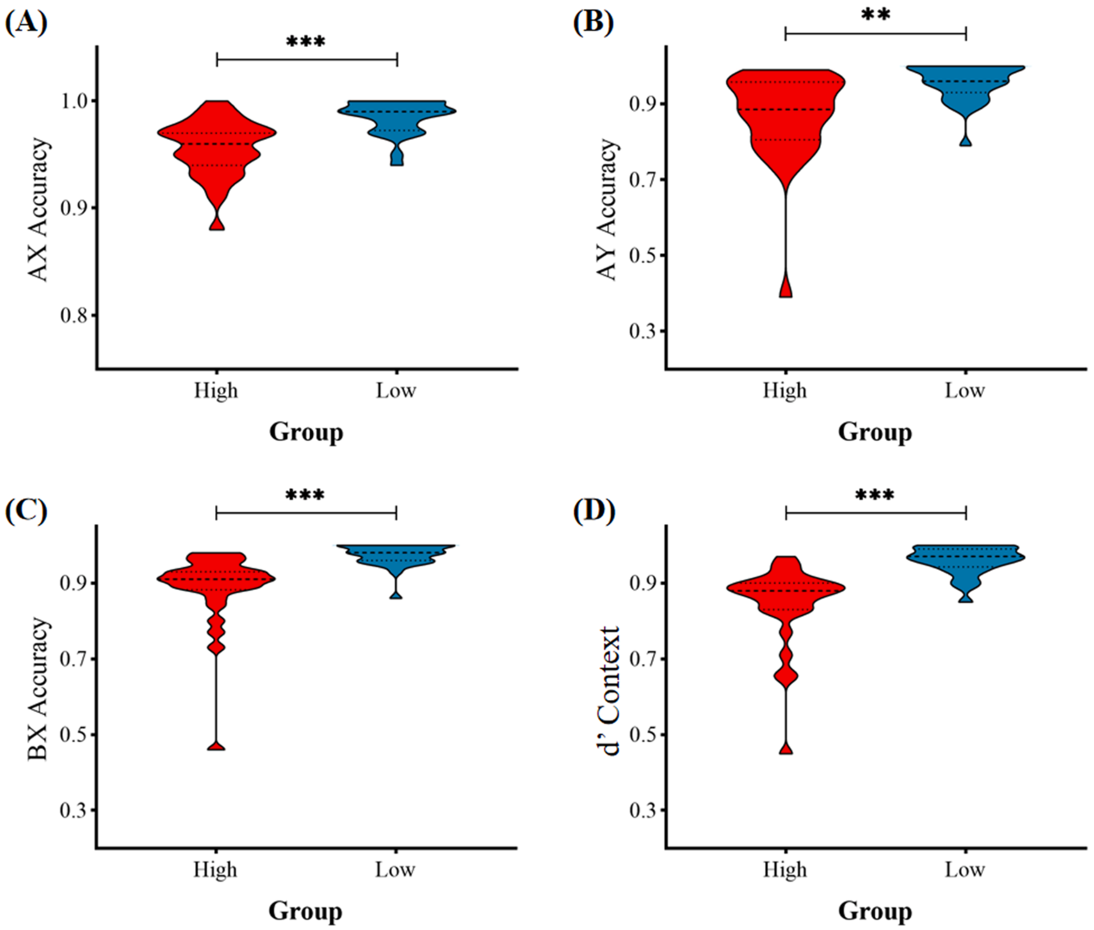

Fig. 3. Chart bars is constructed from the average accuracy and d' of two groups of participants in three conditions. (A) The HTA group demonstrated significantly lower accuracy in the AX pairs compared to the LTA group; (B) The HTA group demonstrated significantly lower accuracy in the AY pairs compared to the LTA group; (C) The HTA group demonstrated significantly lower accuracy in the BX pairs compared to the LTA group; (D) The HTA group demonstrated significantly lower d' Context index compared to the LTA group. * *$P < 0.01$, * **$P < 0.001$. High : High Test Anxiety ; Low : Low Test Anxiety.

Table 2
The Means and SD of amplitudes for the different ERP components and experimental conditions.

	Cue-locked			Probe-locked											
	CNV			N2-Fz			N2-FCz						P3-Pz		
	AX	AY	BX	AX	AY	BX	AX	AY	BX	AX	AY	BX	AX	AY	BX
High	−1.70	−0.84	−1.85	−2.07	−2.36	−3.20	−0.85	−1.20	−2.13	2.66	3.67	1.80	−0.26	1.13	0.45
	(2.15)	(2.15)	(1.97)	(3.48)	(3.25)	(3.21)	(2.88)	(2.70)	(2.74)	(2.76)	(3.37)	(2.58)	(2.35)	(3.41)	(2.87)
Low	−1.91	−1.09	−3.65	−1.75	−2.93	−1.96	−1.07	−2.20	−1.16	3.04	3.45	2.61	−0.31	1.94	0.44
	(1.69)	(2.48)	(3.17)	(2.40)	(2.83)	(2.91)	(2.47)	(2.84)	(3.28)	(2.59)	(2.43)	(2.56)	(1.77)	(2.39)	(2.80)

indicates that the HTA group lacks sustained cue maintenance for the BX, which is a manifestation of lacking active control. This interpretation is corroborated by the high correlation between CNV and d′ Context index, such that participants with larger CNV amplitudes typically exhibit lower d′ Context index (Jonkman, 2006).

The results of the N2 component, representing individual conflict monitoring ability, indicate that the LTA group exhibited significantly greater amplitude under the AY pairs compared to AX and BX. The increase in AY amplitude is attributed to the AY serving as a reactive control condition, requiring individuals to invest more cognitive resources in conflict detection to make correct responses (Nick et al., 2004; Righi et al., 2009; Sehlmeyer et al., 2010). In the HTA group, the BX amplitude was significantly greater than that AX, with no significant difference from AY. In the BX pairs, as the X stimulus was more closely associated with A and was automatically interpreted as another response. Participants likely reassessed the cue B repeatedly when BX appeared to ensure a distinct reaction from the AX condition, thus resulting in a larger N2 amplitude for those with high exam anxiety when facing BX pairs.((Rico-Picó et al., 2021). Additionally, compared to the LTA group, HTA participants exhibited a lack of active cue maintenance, requiring more resources to sustain cognitive activities when BX occurred, resulting in a significantly larger amplitude of the N2 in the BX. The comparison revealed that despite significant differences in behavioral outcomes between the two groups, there were no significant differences in the average amplitude of the N2 component in the AY pairs, which contradicts previous research. Studies have found that with age, individuals with better conflict monitoring abilities show a relatively smaller N2 amplitude in the cognitive conflict, which is considered indicative of more effective conflict monitoring capabilities (Hämmerer et al., 2010; Lo, 2018). In this study, no difference was

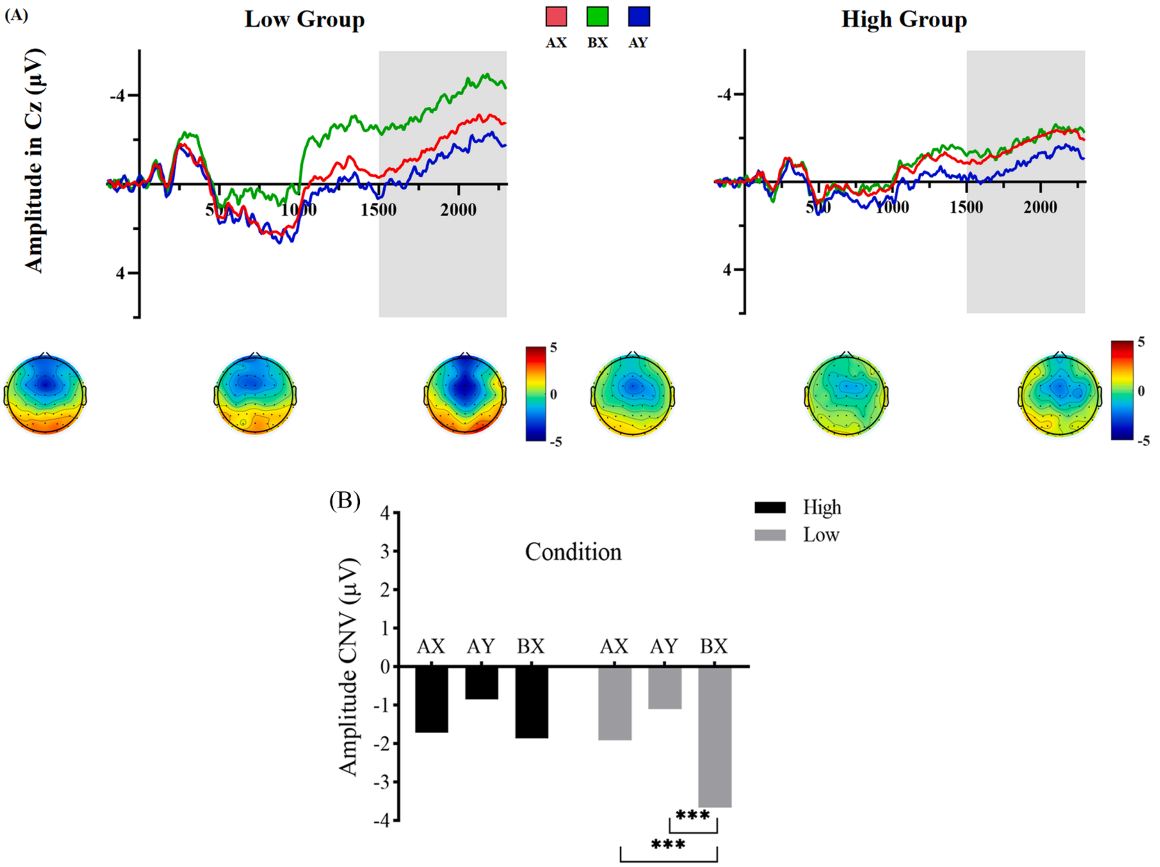

Fig. 4. (A) Waveforms and topographical maps of CNV for the two groups. Topographical maps were constructed using the mean amplitude for the CNV period (1500–2300 ms). (B) Bar chart of the amplitude of CNV along the Cz channel between 1500 and 2300 ms. * **$P < 0.001$. High : High Test Anxiety ; Low : Low Test Anxiety.

observed in the N2 amplitude in the AY pairs between the two groups, likely because HTA individuals, due to their lack of proactive control abilities, require more cognitive resources for conflict monitoring in the BX pairs. This necessitates the allocation of limited cognitive resources to both AY and BX scenarios simultaneously during task execution, resulting in inadequate cognitive resources in the AY pairs and a reduced N2 amplitude. Consequently, despite no difference in N2 amplitude, significant behavioral outcome differences were observed between the two groups. This finding substantiates the dual-role theory of the ACC in both proactive and reactive control. Firstly, the ACC can initiate top-down control and enhance response-related preparation, thereby increasing proactive control over subsequent trials. Secondly, the role of ACC in conflict monitoring can promote reactive control in detecting and resolving conflicts (Jimura et al., 2010; Paxton et al., 2008). The findings of this study further corroborate the theory that when participants possess strong proactive control capabilities, the ACC is activated during the cue-locked to actively maintain an internal representation of environmental information. Due to this proactive maintenance of cues, participants do not need to excessive resources in conflict monitoring for stimulis, resulting in reduced ACC activation and smaller amplitude of the N2 wave during probe-locked. Conversely, if participants have a lack capacity for proactive control, the ACC is either not activated or shows minimal activation during the cue-locked, failing to enhance readiness for subsequent stimulus responses. Therefore, when stimulus X arises, it triggers significant cognitive conflict, activating the ACC which allocates more cognitive resources to assess the conflict, resulting in a larger N2 component.

P3 components often reflect the inhibition costs in the cognitive control process of individuals. We observed larger P3 amplitudes in the AY pairs in both groups, consistent with previous studies (Liu et al., 2011). This may be due to the cue A preparing participants for subsequent stimuli, indicating that cognitive conflicts with small probabilities require stronger reactive inhibition, thus increasing the inhibition cost for participants. In the LTA group, the P3 in the AY pairs was significantly greater than in the BX. This might be because the better proactive control abilities of the LTA group mean that when BX appears, participants do not need to invest additional cognitive resources to inhibit the formed response conflict. In the HTA group, there was also a tendency for the average amplitude of P3 to increase in the BX pairs, which might be due to the lack of effective maintenance of the cue B during the cue-locked, thus requiring more inhibition costs during the probe-locked. Previous research has confirmed this result, indicating that the prefrontal cortex (PFC) plays a crucial role in actively maintaining an internal representation of environmental information, upon which other cognitive processes can be biasedly processed (Miller & Cohen, 2001). Cognitive control is characterized by the processing of task-relevant information while suppressing task-irrelevant information, thereby reducing conflicts and achieving control effects. Proactive control requires maintaining a sustained representation of cue information during the response preparation phase, which demands sustained high activation of the PFC. In contrast, when using reactive control, the PFC needs to retrieve and reactivate cue information to modulate responses after the detection stimulus is presented (Braver et al., 2009). Consequently, the P3 component significantly enlarges.

The results of our study are consistent with the hypothesis, suggesting that individuals with HTA have deficits in proactive control. This can also partially explain the perplexity we raised earlier: why the test as a known stimulus (the time, place and form of the test or evaluation) can still cause individual anxiety. There is a certain correlation between this phenomenon and the lack of proactive control abilities in those with

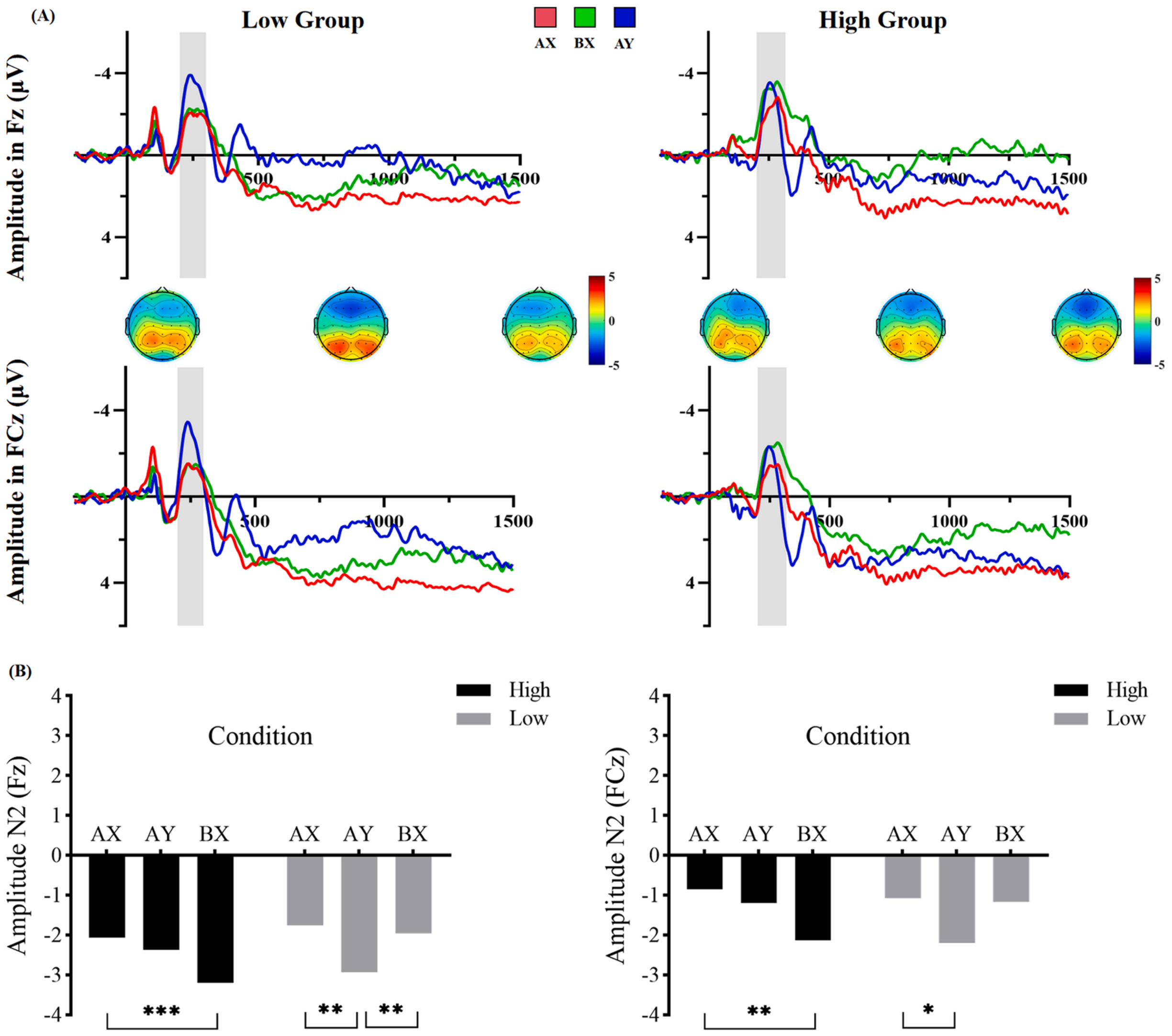

Fig. 5. (A) Waveforms and topographical maps of N2 for the two groups along Fz and FCz. Topographical maps were constructed using the mean amplitude for the N2 period (200–300 ms). (B) Bar chart of the amplitude of N2 along the Fz and FCz channels between 200 and 300 ms. *$P < 0.05$, * *$P < 0.01$, * **$P < 0.001$. High : High Test Anxiety ; Low : Low Test Anxiety.

high test anxiety. Research indicates that differences in individuals' attentional resources may form the basis of their proactive control abilities. Compared to those with less attentional resources, individuals with sufficient attentional resources are more likely to employ proactive control strategies in cognitive activities (Lin et al., 2022). Consequently, individuals with LTA may possess more attentional resources compared to those with HTA. The attention control theory formed around the concept of attention resources is the most recognized theory on the relationship between anxiety and inhibition control. This theory posits that individuals with HTA have stronger expectations and motivations to achieve their goals compared to LTA, often exerting greater effort in task completion, such as increasing the allocation of top-down attentional resources (Eysenck et al., 2007). This also corroborates present study, showing that HTA participants allocate comparable cognitive resources to habitual stimuli (AX) when performing the task, unlike LTA who have more attentional resources. This suggests that individuals with HTA may invest more attentional resources in daily stimuli to facilitate corresponding responses. Therefore, we believe that the increased daily consumption makes it difficult for individuals with HTA, who have relatively limited attentional resources, to allocate more of these resources to cope with high-pressure and high-difficulty tasks when facing test or evaluation situations. The high expectations formed by daily high motivation also bring greater uncontrollable interference to HTA, thereby leading to test anxiety. This is consistent with previous research findings, Wei(2021) suggested that HTA tend to invest more top-down attentional resources when completing tasks. However, when the task demands high attention control, HTA suffers from a lack of top-down attentional resources leading to insufficient involvement.

In summary, this study builds upon previous research to refine hypotheses regarding the cognitive control of test anxiety. Previous studies suggest that individuals with HTA exhibit enhanced activation in relevant brain regions when facing with challenging tasks, employing compensation strategies to compensate for their lack of attention control by increasing top-down proactive control resources. However, these strategies often fail due to the relatively limited attentional resources available to those with high test anxiety, leading to suboptimal task performance (Berggren and Derakshan, 2013; Bishop, 2009). Our results illustrate from the temporal dimension that individuals with HTA may allocate a limited amount of attentional resources to more prevalent general tasks, resulting in insufficient resources available for handling more challenging examinations, which in turn leads to test anxiety.

This study has certain limitations. For instance, the conclusions drawn ultimately were derived based on previous research, lacking measurements of participants' attentional resources during the process,

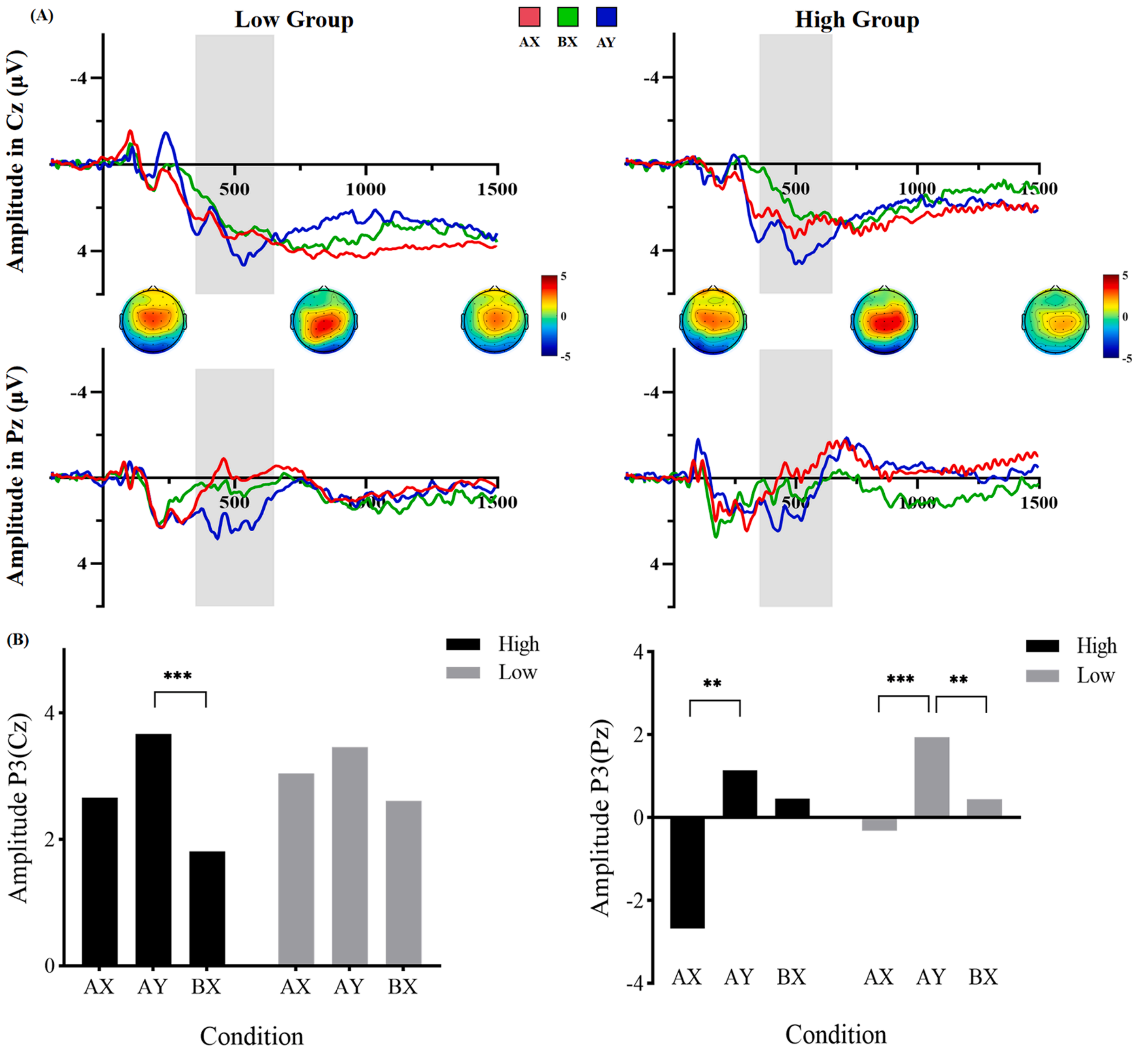

Fig. 6. (A) Waveforms and topographical maps of P3 for the two groups along Cz and Pz. Topographical maps were constructed using the mean amplitude for the P3 period (350–650 ms). (B) Bar chart of the amplitude of P3 along the Cz and Pz channels between 350 and 650 ms. $^{*}P < 0.05$, $^{**}P < 0.01$, $^{***}P < 0.001$. High : High Test Anxiety ; Low : Low Test Anxiety.

which led to less rigorous conclusions. All participants recruited in this study were full-time college students. However, the critical period for the development of test anxiety is during junior and senior high school, when individuals' proactive control abilities are not yet fully developed. Investigating the relationship between test anxiety and proactive control abilities during this period is particularly important for understanding the onset and development of test anxiety. Despite its high temporal resolution, ERPs technology provides a good neurobiological indicator for understanding the relationship between test anxiety and proactive control abilities. However, there are different interpretations of the EEG components generated in different tasks, and different interpretations will affect the reliability of the conclusions of the study. Therefore, a variety of research tasks should be used as far as possible to exclude possible adverse effects on the conclusions. For example, CNV components may be affected by individual motivation and fatigue(Loveless & Sanford, 1974), so more rigorous experimental designs can be used to circumvent these effects. ERPs technology low spatial resolution also limits our further understanding of the relationship between the two. In addition, this paper has limitations in terms of sample size and cross-sectional design.

5. Conclusion

This study found that, compared to individuals with LTA, those with HTA demonstrated a lack of proactive control strategies and lower ability to maintain cues in proactive control tasks, indicating a deficit in proactive control abilities among HTA individuals. This deficit may be one of the causes of test anxiety.

CRediT authorship contribution statement

Renlai Zhou: Writing – review & editing, Validation, Supervision, Project administration, Methodology, Investigation, Funding acquisition, Conceptualization. **Lei wang:** Writing – review & editing, Writing – original draft, Visualization, Validation, Methodology, Formal analysis, Data curation.

Declaration of Generative AI and AI-assisted technologies in the writing process

The author(s) did not use generative AI technologies for preparation of this work.

Declaration of Competing Interest

The authors declare no potential conflict of interests.

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Data availability

Data will be made available on request.

References

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.

Berggren, N., & Derakshan, N. (2013). The role of consciousness in attentional control differences in trait anxiety. *Cognition Emotion, 27*(5), 923–931.

Bishop, S. J. (2009). Trait anxiety and impoverished prefrontal control of attention. *Nature Neuroscience, 12*(1), 92–98.

Braver, T. S. (2012). The variable nature of cognitive control: A dual mechanisms framework. *Trends in Cognitive Sciences, 16*(2), 106–113.

Braver, T. S., Gray, J. R., & Burgess, G. C. (2007). Explaining the many varieties of working memory variation: Dual mechanism of cognitive control. In A. R. A. Conway, C. Jarrold, M. J. Kane, A. Miyake, & J. N. Towse (Eds.), *Variation in working memory* (pp. 76–106). New York: Oxford University Press.

Braver, T. S., Paxton, J. L., Locke, H. S., & Barch, D. M. (2009). Flexible neural mechanisms of cognitive control within human prefrontal cortex. *Proceedings of the National Academy of Sciences of the United States of America, 106*(18), 7351–7356.

Bruder, G. E., Kayser, J., Tenke, C. E., Leite, P., Schneier, F. R., Stewart, J. W., & Quitkin, F. M. (2002). Cognitive ERPs in depressive and anxiety disorders during tonal and phonetic oddball tasks. *Clinical Electroencephalography, 33*(3), 119–124.

Bruin, K. J., & Wijers, A. A. (2002). Inhibition, response mode, and stimulus probability: A comparative event-related potential study. *Clinical Neurophysiology, 113*(7), 1172–1182.

Brunia, C. H. M. (1999). Neural aspects of anticipatory behavior. *Acta Psychologica, 101* (2-3), 213–242.

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.

Burgess, G. C., & Braver, T. S. (2010). Neural mechanisms of interference control in working memory: effects of interference expectancy and fluid intelligence. *Plos One*.

Burgess, G. C., Gray, J. R., Conway, A. R. A., & Braver, T. S. (2011). Neural mechanisms of interference control underlie the relationship between fluid intelligence and working memory span. *Journal of Experimental Psychology: General, 140*(4), 674–692.

Clayson, P. E., Baldwin, S. A., & Larson, M. J. (2013). How does noise affect amplitude and latency measurement of event-related potentials (ERPs)? *A methodological critique and simulation study*. *Psychophysiology, 50*(2), 174–186.

Cocchi, L., Zalesky, A., Fornito, A., & Mattingley, J. B. (2013). Dynamic cooperation and competition between brain systems during cognitive control. *Trends Cogn Sci, 17* (10), 493–501.

Cohen, J. D., Barch, D. M., Carter, C., & Servan-schreiber, D. (1999). Context-processing deficits in schizophrenia: Converging evidence from three theoretically motivated cognitive tasks. *Journal of Abnormal Psychology, 108*(1), 120–133.

Corbetta, M., & Shulman, G. L. (2002). Control of goal-directed and stimulus-driven attention in the brain. *Nature Publishing Group, 3*.

DeWall, C. N., Baumeister, R. F., Mead, N. L., & Vohs, K. D. (2011). How leaders self-regulate their task performance: Evidence that power promotes diligence, depletion, and disdain. *Journal of Personality and Social Psychology, 100*(1), 47–65.

Diamond, A. (2013). Executive functions. *Annual Review of Psychology, 64*, 135–168.

Eysenck, M. W., & Byrne, A. (1992). Anxiety and susceptibility to distraction. *Personality and Individual Differences, 13*(7), 793–798.

Eysenck, M. W., & Derakshan, N. (2011). New perspectives in attentional control theory. *Personality Individual Differences, 50*(7), 955–960.

Eysenck, M. W., Derakshan, N., Santos, R., & Calvo, M. G. (2007). Anxiety and cognitive performance: attentional control theory. *Emotion, 7*(2), 336–353.

Fales, C. L., Barch, D. M., Burgess, G. C., Schaefer, A., Mennin, D. S., Gray, J. R., & Braver, T. S. (2008). Anxiety and cognitive efficiency: Differential modulation of transient and sustained neural activity during a working memory task. *Cognitive, Affective, Behavioral Neuroscience, 8*(3), 239–253.

Faul, F., Erdfelder, E., Lang, A. G., & Buchner, A. (2007). G*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods, 39*(2), 175–191.

Gonthier, C., Macnamara, B. N., Chow, M., Conway, A. R. A., & Braver, T. S. (2018). Inducing proactive and reactive control shifts in the ax-cpt. *Frontiers in Psychology, 7*.

Hämmerer, D., Li, S. C., Müller, V., & Lindenberger, U. (2010). An electrophysiological study of response conflict processing across the lifespan: Assessing the roles of conflict monitoring, cue utilization, response anticipation, and response suppression. *Neuropsychologia, 48*(11), 3305–3316.

Karatas, H. B. H. (2013). Correlation among high school senior students' test anxiety, academic performance and points of university entrance exam. *Educational Research Reviews, 8*(13), 919–926.

Hembree, R. (1988). Correlates, causes, effects, and treatment of test anxiety. *Review of Educational Research, 58*(1), 47–77.

Hill, K. T., & Wigfield, A. (1984). Test anxiety: a major educational problem and what can be done about it. *Elementary School Journal, 85*(1), 105–126.

Rico-Picó, J., Hoyo, A., Guerra, S., Conejero, A., & Rueda, M. R. (2021). Behavioral and brain dynamics of executive control in relation to children's fluid intelligence. *Intelligence, 84*, 1–11.

Jimura, K., Locke, H. S., & Braver, T. S. (2010). Prefrontal cortex mediation of cognitive enhancement in rewarding motivational contexts. *Proceedings of the National Academy of Sciences of the United States of America, 107*(19), 8871–8876.

Jonkman, L. M. (2006). The development of preparation, conflict monitoring and inhibition from early childhood to young adulthood; a go/Nogo ERP study. *Brain Research, 1097*(1), 181–193.

Karayanidis, F., & Jamadar, S. D. (2014). Event-related potentials reveal multiple components of proactive and reactive control in task switching. In J. A. Grange, & G. Houghton (Eds.), *task switching and cognitive control* (pp. 200–236). New York: Oxford University Press.

Knott, J. R., & Irwin, D. A. (1968). Anxiety, stress and contingent negative variation (CNV). *Electroencephalography and Clinical Neurophysiology, 24*(3), 286–287.

Lin, Y., Brough, R. E., Tay, A., Jackson, J. J., & Braver, T. S. (2022). Working Memory Capacity Preferentially Enhances Implementation of Proactive. *Control Journal of Experimental Psychology: Learning, Memory, and Cognition*, 1–19.

Liu, T., Xiao, T., Shi, J., & Zhao, D. (2011). Response preparation and cognitive control of highly intelligent children: A go-Nogo event-related potential study. *Neuroscience, 180*, 122–128.

Lo, S. L. (2018). A meta-analytic review of the event-related potentials (ern and n2) in childhood and adolescence: providing a developmental perspective on the conflict monitoring theory. *Developmental Review, 48*, 82–112.

Lotz, C., & Sparfeldt, J. R. (2017). Does test anxiety increase as the exam draws near?– Students' state test anxiety recorded over the course of one semester. *Personality and Individual Differences, 104*, 397–400.

Loveless, N. E., & Sanford, A. J. (1974). Slow potential correlates of preparatory set. *Biological Psychology, 1*(4), 303–314.

Macar, F., Vidal, F., & Casini, L. (1999). The supplementary motor area in motor and sensory timing: Evidence from slow brain potential changes. *Experimental Brain Research, 125*, 271–280.

Miller, E. K., & Cohen, J. D. (2001). An integrative theory of prefrontal cortex function. *Annual Review of Neuroscience, 24*(1), 167–202.

Morales, J., Yudes, C., Gómez-Ariza, C. J., & Bajo, M. T. (2015). Bilingualism modulates dual mechanisms of cognitive control: Evidence from ERPs. *Neuropsychologia, 2015*, 157–169.

Nathaniel, V. D. E., Jester, D., Roy, D., & Post, J. (2017). Test anxiety effects, predictors, and correlates: a 30-year meta-analytic review. *Journal of Affective Disorders*, 483.

Nazanin, D., & Eysenck, M. W. (2009). Anxiety, processing efficiency, and cognitive performance new developments from attentional control theory. *European Psychologist, 14*(2), 168–176.

Newman, E. (1996). No more test anxiety: Effective steps for taking tests and achieving better grades. *Learning Skillspubns*.

Nick, Yeung, Matthew, M., Jonathan, Botvinick, et al. (2004). The neural basis of error detection: conflict monitoring and the error-related negativity. *Psychological Review*.

Nieuwenhuis, S., Yeung, N., Wildenberg, W., & 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.

Pacheco-Unguetti, A. P., Acosta, A., Callejas, A., & Lupiáñez, J. (2010). Attention and anxiety: different attentional functioning under state and trait anxiety. *Psychological Science, 21*(2), 298–304.

Paxton, J. L., Barch, D. M., Racine, C. A., & Braver, T. S. (2008). Cognitive control, goal maintenance, and prefrontal function in healthy aging. *Cerebral Cortex, 18*(5), 1010–1028.

Petersen, S. E., & Posner, M. I. (2012). The attention system of the human brain: 20 years after. *Annual Review of Neuroscience, 35*(1), 73–89.

Pfefferbaum, A., Ford, J. M., Weller, B. J., & Kopell, B. S. (1985).). *ERPs to Response Production and inhibition Electroencephalography and Clinical Neurophysiology, 60*(5), 423–434.

Pilar, Lopez-Garcia, Tyler, A., Lesh, & Taylor, et al. (2015). The neural circuitry supporting goal maintenance during cognitive control: a comparison of expectancy ax-cpt and dot probe expectancy paradigms. *Cognitive, Affective, Behavioral Neuroscience, 16*, 64–175.

Pires, L., Leitão, J., Guerrini, C., et al. (2014). Event-Related Brain Potentials in the Study of Inhibition: Cognitive Control, Source Localization and Age-Related Modulations. *Neuropsychol Rev, 24*, 461–490.

Redick, T. S. (2014). Cognitive control in context: Working memory capacity and proactive control. *Acta Psychologica, 145*(1), 1–9.

Richmond, L. L., Redick, T. S., & Braver, T. S. (2015). Remembering to prepare: The benefits (and costs) of high working memory capacity. *Journal of Experimental Psychology Learning, Memory, and Cognition, 41*(6), 1764–1777.

Righi, S., Mecacci, L., & Viggiano, M. P. (2009). Anxiety, cognitive self-evaluation and performance: ERP correlates. *Journal of Anxiety Disorders, 23*(8), 1132–1138.

Sehlmeyer, C., Konrad, C., Zwitserlood, P., Arolt, V., Falkenstein, M., & Beste, C. (2010). Erp indices for response inhibition are related to anxiety-related personality traits. *Neuropsychologia, 48*(9), 2488–2495.

Shen, A., Zhao, W., Han, B., Zhang, Q., Zhang, Z., Chen, X., & Li, J. (2018). The contribution of the contingent negative variation (CNV) to goal maintenance. *Schizophrenia Research, 195*, 372–377.

Smith, J. L., Johnstone, S. J., & Barry, R. J. (2006). Effects of pre-stimulus processing on subsequent events in a warned go/NoGo paradigm: Response preparation, execution and inhibition. *International Journal of Psychophysiology, 61*(2), 121–133.

Szafranski, D., Fletcher, T., & Norton, P. (2012). Test anxiety inventory: 30 years later. *Anxiety Stress and Coping, 25*(6), 667–677.

Van Veen, V., & Carter, C. S. (2002). The tinning of action-monitoring processes in the anterior cingulate cortex. *Journal of Cognitive Neuroscience, 14*(4), 593–602.

Walter, W. G., Cooper, R., Aldridge, V. J., et al. (1964). Contingent negative variation: An electric sign of sensorimotor association and expectancy in the human brain. *Nature, 203*, 380–384.

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.

Wessel, J. R. (2018). Prepotent motor activity and inhibitory control demands in different variants of the go/no-go paradigm. *Psychophysiology, 55*, 3.

Xu, M., Li, Z., Qi, S., Fan, L., Zhou, X., & Yang, D. (2020). Social exclusion modulates dual mechanisms of cognitive control: Evidence from ERPs. *Human Brain Mapping, 41* (10), 2669–2685.

Zamani, A., & Pouratashi, M. (2018). The relationship between academic performance and working memory, self-efficacy belief, and test anxiety. *Journal of School Psychology, 6*(4), 25–44.

Zeidner, M. (1998). *Test anxiety: the state of the art*. Plenum Press.

Zeidner, M. (2007). *Test Anxiety in Educational Contexts*. Elsevier Inc.

Zhang, Y., Li, Q., Wang, Z., Liu, X., & Zheng, Y. (2017). Temporal dynamics of reward anticipation in the human brain. *Biological Psychology, 128*, 89–97.

Zink, N., Lenartowicz, A., & Markett, S. (2021). A new era for executive function research: On the transition from centralized to distributed executive functioning. *Neurosci Biobehav Rev, 124*, 235–244.