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The influence of punishment anticipation on inhibitory control processing in individuals with test anxiety

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ABSTRACT

Using the event-related potential (ERP) method combined with the monetary incentive delay task and arrow Flanker Task, this study investigated the impact of varying punishment anticipation on inhibitory control processing in individuals with test anxiety. Results revealed that during the cue processing, compared to individuals with low test anxiety (LTA), individuals with high test anxiety (HTA) exhibited more negative cue-N2 and CNV amplitudes under high punishment conditions. In the inhibitory control processing, under high punishment conditions, HTA individuals showed more negative N2 amplitudes in incongruent trials compared to LTA individuals. Under no-punishment conditions, HTA individuals demonstrated more positive P3 and conflict SP amplitudes in incongruent trials. The study suggests that excessive punishment anticipation for failure consequences may constitute the mechanism underlying inhibitory control deficits in individuals with HTA. These findings provide a new perspective for understanding the inhibitory control deficits in HTA and offer foundations for targeted interventions.

1. Introduction

Test anxiety refers to anxiety arising from fear of failure in examination or evaluative situations, accompanied by significant physiological (e.g., increased heart rate, elevated skin conductance), cognitive (e.g., attentional distraction, enhanced negative thinking), and behavioral (e.g., avoidance strategies) changes (Cassady & Johnson, 2002). Studies have shown that test anxiety impairs cognitive performance, particularly inhibitory control (Huang et al., 2022; Wei et al., 2021; Zhang et al., 2019). Such effects have been observed in prior research, where individuals engaged more top-down attentional resources and exerted greater effort to maintain task performance (Eysenck et al., 2007; Wei et al., 2022).

Executive functions refer to top-down mental processes necessary for goal-directed behavior, with inhibitory control being one of their core components. Inhibitory control enables individuals to resist automatic or prepotent responses, ignore distractions, and modulate affective reactions in the service of adaptive behavior. Inhibitory control is also critical for emotional regulation, academic success, and mental health (Diamond, 2013). The importance of inhibitory control is magnified in evaluative environments like examination settings, where emotional interference must be inhibited to maintain cognitive performance. Such demands pose unique challenges for individuals with high test anxiety (HTA), whose cognitive resources are overtaxed by heightened affective reactivity (Spielberger et al., 2015).

Examination settings provide a salient example of such high-demand contexts, where individuals must suppress distractions arising from internal stress responses and maintain focused attention on task-relevant information. The core characteristic of test anxiety is its specific reactivity to evaluative situations, which plays a central role in disrupting performance (Von der Embse et al., 2018). Individuals with HTA perceived tests as threats, generating excessive worry that increased the burden on inhibitory control and severely disrupted task processing (Spielberger et al., 2015). Previous studies simulating test-related stress scenarios in laboratory settings have revealed distinct inhibitory control processing patterns in HTA individuals. Previous research has indicated that in threatening contexts, individuals with HTA tend to mobilize enhanced top-down attentional control resources to maintain task performance, a compensatory mechanism neurally manifested as significant augmentation of N2 amplitudes (Wei et al., 2022). The N2 component, peaking around 250–350 ms post-stimulus over fronto-central areas, indexed conflict monitoring (Kopp et al., 2010;

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Botvinick et al., 2004; Donkers & van Boxtel, 2004). Studies demonstrated that incongruent trials elicited more negative N2 amplitudes compared to congruent trials (Kok, 1986; Nieuwenhuis et al., 2003).

HTA individuals not only faced generalized inhibitory control challenges but also have been shown to demonstrate significantly impaired suppression of threat-related stimuli (whether test-relevant or not) under stressful conditions (Keogh & French, 2001). According to attentional control theory (Eysenck & Derakshan, 2011), when task difficulty escalates beyond the threshold of resource compensation, systematic performance decline occurs in anxious individuals (Derakshan & Eysenck, 2009). This theoretical prediction has been empirically validated. Wei et al. (2021) found that under combined pressures of evaluative contexts, high cognitive load, and incongruent conditions, HTA individuals exhibited reduced N2 amplitudes, which may reflect neural correlates of impaired inhibitory control. Similarly, Angelidis et al. (2019) demonstrated that the compounding effects of stressful environments and high task demands led to diminished inhibitory control efficacy against negative distractors in HTA individuals.

While previous studies (e.g., Angelidis et al., 2019; Wei et al., 2021; Wei et al., 2022) have demonstrated that test-related evaluative contexts can impair inhibitory control, they have yet to clarify the internal psychological mechanisms underlying this effect in individuals with HTA. We suggest that in HTA individuals, such evaluative contexts elicit catastrophic expectations about exam failure, giving rise to heightened anticipation of punishment even before task engagement. This negativity amplification may bias attentional and control resources toward avoiding potential failure (Robinson & Liu, 2013). Initially, HTA individuals may over-engage attentional control to maintain performance, but as cognitive demands increase, their compensatory capacity may be exceeded, resulting in impaired task performance. The present study investigates how punishment anticipation, as a contributing factor, is associated with inhibitory control impairments in HTA individuals.

According to the Expected Value of Control (EVC) theory (Shenhav et al., 2013), the higher the expected value of a task, the greater the motivation for an individual to take action and strive to achieve the anticipated outcome. In the evaluative contexts, individuals with HTA might exhibit inhibitory control deficits because they have overly high expectations regarding the potential losses associated with evaluative situations, leading to excessive resource consumption. From a personality trait perspective, HTA individuals exhibit heightened punishment sensitivity, which forms a bidirectional reinforcement cycle with negative expectations (Stoeber & Corr, 2017). This relationship is grounded in Reinforcement Sensitivity Theory, which posits that individual differences in reactivity to punishment and reward stem from underlying variations in the behavioral inhibition system (BIS) and behavioral activation system (BAS) (Gray & McNaughton, 2000; Corr, 2008). The BIS is especially responsive to signals of punishment, threat, and novelty, triggering increased vigilance, anxiety, and behavioral avoidance in the face of potential negative outcomes. In contrast, the BAS is sensitive to cues of reward and drives approach behavior. Within this framework, Nob (2013) found that HTA individuals show hypersensitivity to the BIS, making them especially reactive to adverse events such as failure or punishment. Neuroimaging studies have also provided evidence for heightened punishment sensitivity, showing that exposure to loss-related cues is associated with increased functional connectivity between the amygdala and hippocampus (Hahn et al., 2010). These findings suggest that HTA individuals are more likely to perceive evaluative contexts as threatening, even when such contexts are objectively neutral.

Building on these findings, we propose that inhibitory control deficits in HTA individuals were associated with heightened negative expectations of punishment. To examine the impact of punishment anticipation on inhibitory control, the study employed an incentivized Flanker task, which integrated the monetary incentive delay task (Knutson et al., 2001) and the arrow Flanker task (Forster et al., 2011). By introducing graded punishment cues, we manipulated punishment anticipation levels during inhibitory control tasks and systematically assessed neurocognitive effects of this anticipation on HTA individuals. In the adapted monetary incentive delay task, punishment magnitudes (no: −0; low: −10; high: −100) were visually cued through standardized symbols to inform participants of the upcoming task's punishment level. Participants were instructed to execute rapid directional judgments upon target stimulus onset to minimize penalty accrual.

Research has shown that presenting punishment cues before each trial increases participants' readiness and effectively regulates cognitive activities (Botvinick & Braver, 2015), thereby enhancing cognitive control (Cubillo et al., 2019). Consistently, Insel et al. (2019) demonstrated that learned high-loss cues enhanced inhibitory performance in late adolescents, accompanied by increased recruitment of frontostriatal circuitry. Raab and Hartley (2020) similarly found that aversive reinforcement histories facilitated response inhibition across development. Moreover, Heffer et al. (2024) found that higher punishment sensitivity was associated with improved response inhibition. These findings support the idea that motivational salience, particularly that associated with punishment, can enhance cognitive control through increased attentional allocation and proactive engagement.

However, the cognitive benefits of punishment cues may depend on individual differences in punishment sensitivity. For example, Braem et al. (2013) reported that while low punishment-sensitive individuals exhibited improved conflict adaptation after punishment, those with high punishment sensitivity showed increased reaction times (RTs). Similarly, Moutoussis et al. (2018) reported that aversive reinforcement could distort value-based decision-making. This pattern may reflect the competitive interaction between aversive emotional responses and executive control systems. As discussed by Shackman et al. (2011), excessive negative affect could divert frontocingulate resources normally dedicated to cognitive regulation, potentially impairing goal-directed behavior under threat. Taken together, these findings imply that although punishment cues can enhance cognitive control under typical conditions, their effects may be reversed in individuals with HTA, where heightened punishment sensitivity and aversive over-reactivity could overload rather than support control-related processes.

This study employed the ERP method (Luck, 2023) to further elucidate underlying neural processes. The ERP components of interest included those related to cue processing—cue-N2, cue-P3, and contingent negative variation (CNV)—and those associated with inhibitory control processing—N2, P3, and conflict-related slow potential (SP). During cue processing, the cue-N2 is a negative component emerging approximately 200–300 ms post-cue stimulus over fronto-central regions (Santesso et al., 2012). Previous ERP research has demonstrated that punishment cues elicit stronger cue-N2 amplitudes, suggesting greater allocation of attentional resources to avert anticipated losses (Novak and Foti, 2015; Potts, 2011). The cue-P3, a positive component peaking around 250–500 ms after cue onset, was linked to attentional resource distribution and motivational salience (Broyd et al., 2012; Van den Berg et al., 2012). Unlike cue-N2, cue-P3 was generally insensitive to cue valence during processing, with both reward and punishment cues typically evoking larger amplitudes. The CNV manifests during the interval between cue and target stimuli, spanning from hundreds of milliseconds to several seconds until target onset (Kononowicz & Penney, 2016). It reflected anticipation of upcoming stimuli and was associated with response preparation, preparatory attention, and motivational engagement (Schevernels et al., 2014).

In addition to the N2 component, the present study also focused on the P3 and conflict slow potential (SP) components during the Flanker task. The P3, typically observed over centro-parietal regions between 300 and 500 ms post-stimulus, has been associated with the allocation and engagement of cognitive control resources (Randall and Smith, 2011; West et al., 2005), particularly in support of response inhibition and conflict resolution (Chen et al., 2008; Gajewski and Falkenstein, 2013; Groom and Cragg, 2015). The conflict SP is a sustained positive-going waveform that emerges approximately 500 ms post-stimulus at centro-parietal sites. It is thought to reflect later-stage processes related to conflict resolution, including attentional reconfiguration and post-conflict behavioral adjustment (Hu et al., 2012; Larson et al., 2009). Notably, incongruent trials have been shown to elicit significantly larger conflict SP amplitudes compared to congruent trials.

This study aimed to investigate the impact of punishment anticipation on inhibitory control in individuals with HTA. We hypothesized that HTA individuals would exhibit slower RTs and decreased accuracy on incongruent trials under punishment cues, relative to LTA individuals. During the cue processing, compared to LTA individuals, HTA individuals would exhibit larger cue-N2, cue-P3, and CNV amplitudes under high punishment conditions. In the Flanker task processing, under high punishment conditions, HTA individuals would display enhanced N2 amplitudes, reduced P3 amplitudes, and diminished conflict SP amplitudes in incongruent trials relative to LTA individuals.

2. Methods

2.1. Participants

Participants were recruited via online platforms and posters. A total of 384 undergraduates from Nanjing University were assessed using the Chinese version of the Test Anxiety Scale (TAS-C; Wang, 2003) and the Beck Depression Inventory-II (BDI-II-C). Inclusion criteria: TAS scores $\geq$ 20 (high test anxiety) or $\leq$ 12 (low test anxiety; Wei et al., 2022); BDI-II-C scores $\leq$ 13 to exclude potential confounding effects of depressive symptoms. Consistent with prior ERP research on test anxiety (Zhang et al., 2019), 65 participants were initially recruited (32 high test anxiety, 33 low test anxiety). After excluding data from 2 HTA and 3 LTA participants due to excessive head/eye movements, 60 participants were retained for analysis. The final sample comprised 30 HTA participants (20.90 ± 2.39 years, 17 females) and 30 LTA participants (21.63 ± 2.93 years, 14 females).

All were right-handed, had normal or corrected vision, had no psychiatric history, and provided informed consent. Participants received 40–80 yuan based on task performance. The study was approved by the Ethics Committee of Nanjing University (NJUPSY202403001).

2.2. Design and procedure

A mixed 2 (Test Anxiety: high/low) × 3 (Punishment Cue: none/low/high) × 2 (Congruency: congruent/incongruent) design was used. Participants viewed cues (-0, −10, −100) indicating potential point losses (none, low, or high punishment) in an arrow Flanker task (Forster et al., 2011). The task required judging the direction of a central arrow while ignoring flanking distractors.

Before the experiment, participants were informed about the noninvasive nature of EEG recording. After signing consent forms, participants washed and dried their hair. They were seated 60 cm from a computer screen in a sound-attenuated EEG lab and instructed to maintain central fixation while minimizing facial/head movements.

A 12-trial practice block preceded the formal experiment. Instructions clarified that cues (-0/-10/-100) indicated potential point losses for errors/slow responses, with cumulative penalties affecting final payment. The formal experiment comprised 360 trials (60 congruent/incongruent trials per cue type, randomized). Breaks occurred every 120 trials. The 20-minute experiment was programmed in E-Prime with white stimuli on a black background.

We used a modified version of the Flanker task (Forster et al., 2011) with embedded punishment cues (Knutson et al., 2001). Each trial began with an 800–1200 ms fixation cross, followed by a 1000 ms punishment cue. After a 100-ms flanker preview, full arrow stimuli appeared (maximum response window: 1400 ms). Participants pressed "F" (left) or "J" (right) to indicate the central arrow's direction. Participants were instructed to respond as quickly and accurately as possible within the 1400-ms response window. After the response, a 1000-ms blank screen was presented; if a participant responded incorrectly or too slowly, the word “LOSE” appeared on the screen. No feedback was provided for correct responses to maintain a punishment context and avoid introducing positive reinforcement cues (see Fig. 1). Participants started with an initial score of 0 points. On each trial, incorrect or slow responses triggered point deductions based on the punishment cue condition (none, low, or high). The losses were accumulated throughout the task, and the final monetary reward was calculated by subtracting the total lost points from a base payment. This design was intended to maintain a continuous punishment context and increase participants' sensitivity to performance-related losses.

2.3. EEG data recording and analysis

EEG data were recorded using a 64-channel ESI-64 system (Scan 4.5, Neurosoft Labs, Inc.). Scalp potentials were collected via Ag/AgCl electrodes mounted on a cap following the international 10–20 system. The left mastoid served as the online reference, with the forehead as the ground. Data were filtered with a 0.05–100 Hz bandpass and sampled at 1000 Hz, with electrode impedances maintained below 10 kΩ.

During offline analysis, we used EEGLAB (Version 13.0.0.0b), an open toolbox based on the MATLAB environment, for preprocessing. First, electrode positions were identified. Next, the average of the left and right mastoids was used as a new reference electrode to re-reference the recorded data. The data were band-pass filtered between 0.01 and 40 Hz, and the sampling rate was reduced to 500 Hz per channel. Independent component analysis (ICA) guided by the ICLabel classification algorithm was used to correct artifacts such as eye and muscle activity.

Preprocessed EEG data were segmented based on two key events: cue stimuli (-200–1000 ms) and congruency stimuli (-200–1000 ms). Baseline correction was performed using the mean amplitude before the cue stimulus (-200–0 ms). Finally, artifacts exceeding ±100 μV were automatically removed, and data from each participant under each condition were averaged. Data were considered valid if more than 75 % of trials for each condition were retained. Based on these criteria, 2 HTA and 3 LTA participants were excluded from the final ERP analyses.

All electrode selections and time windows were determined based on established criteria from previous literature (Glazer et al., 2018; Larson et al., 2014; Wei et al., 2022) and further optimized according to the spatial distribution characteristics of the experimental data. The following electrode selection and time windows were applied for analyzing ERP components: during the cue processing, for the cue-N2 component, data were averaged from the frontal electrodes Fz and FCz, with a time window of 250–350 ms (Potts, 2011). The cue-P3 component was analyzed using the POz electrode in the parieto-occipital region, with a time window of 370–470 ms (Broyd et al., 2012). The CNV component was analyzed using the FCz electrode in the frontocentral region, covering a time window of 550–750 ms (Kononowicz & Penney, 2016). During the Flanker task processing, the N2 component was analyzed using the FCz electrode in the frontocentral region, with a time window of 380–440 ms (Pan et al., 2020). The P3 component was analyzed using the mean amplitude from the centroparietal electrodes CPz, CP1, and CP2, within a time window of 450–550 ms (Hsieh, Huang, Wu, Chang, & Hung, 2018). The conflict SP component was analyzed using the mean amplitude from Cz and CPz electrodes in the centroparietal region, with a time window of 600–800 ms (Hu et al., 2012). For illustration, although the analyses were conducted on averaged electrode data, only the representative channel is shown in the following ERP figures.

2.4. Data analysis

Behavioral and ERP data were analyzed using repeated-measures ANOVAs conducted in SPSS 27.0. The Greenhouse-Geisser correction

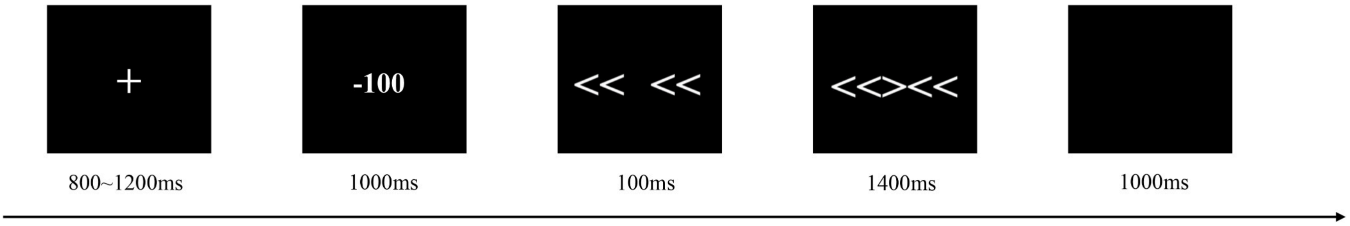

Fig. 1. Experimental task flowchart of this study. Using the high-punishment incongruent trial as an example.

was applied when the assumption of sphericity was violated, and Bonferroni corrections were used for all pairwise comparisons and simple effects. Extreme RTs beyond ±3 SDs from each participant's mean were removed from behavioral analysis. Only correct trials were included in the analyses of RTs and mean ERP amplitudes.

For the behavioral data (RTs and accuracy), a 2 (test anxiety: high, low)× 3 (punishment cue: none, low, high)× 2 (congruency: congruent, incongruent) repeated-measures ANOVA was conducted. For the ERP data, cue-N2, cue-P3, and CNV were each analyzed using a 2 (test anxiety: high, low)× 3 (punishment cue: none, low, high) repeated-measures ANOVA. N2, P3, and conflict SP during the Flanker task were each analyzed using a 2 (test anxiety: high, low)× 3 (punishment cue: none, low, high)× 2 (congruency: congruent, incongruent) repeated-measures ANOVA.

2.5. *Transparency and openness*

We report how we determined our sample size, all data exclusions, all manipulations, and all measures in the study. All data, analysis code, and research materials are available on request to the corresponding author. Data were analyzed using EEGLAB (Version 13.0.0.0b) and SPSS (Version 27.0). This study's design and its analysis were not pre-registered.

3. Results

3.1. *Behavioral results*

3.1.1. *RTs*

The main effect of punishment cues was significant, $F(2116)= 27.23$, $\varepsilon= .79$, $p < .001$, $\eta_p^2= .319$. Post hoc multiple comparisons revealed that RTs under the no-punishment condition (411.02 ± 5.85 ms) were significantly faster than those under the low-punishment condition (416.28 ± 5.81 ms, $p < .001$) and the high-punishment condition (420.79 ± 6.07 ms, $p < .001$). Additionally, RTs in the low-punishment condition were significantly faster than those in the high-punishment condition ($p < .001$) (see Fig. 2A).

The main effect of congruency was significant, $F(1,58)= 470.14$, $p < .001$, $\eta_p^2= .890$. Post hoc tests showed that RTs for incongruent trials (454.57 ± 6.35 ms) were significantly slower than those for congruent trials (377.48 ± 5.89 ms) (see Fig. 2B).

The interaction between punishment cues and congruency was significant, $F(2116)= 3.30$, $p = .041$, $\eta_p^2= .054$. Simple effects analysis revealed the following patterns: Under the congruent trials, RTs in the no-punishment condition (370.55 ± 5.82 ms) were significantly faster than those in the low-punishment condition (378.93 ± 6.11 ms, $p < .001$) and the high-punishment condition (382.98 ± 6.02 ms, $p < .001$). Moreover, RTs in the low-punishment condition were significantly faster than those in the high-punishment condition ($p = .041$).

Under incongruent trials, RTs in the no-punishment condition

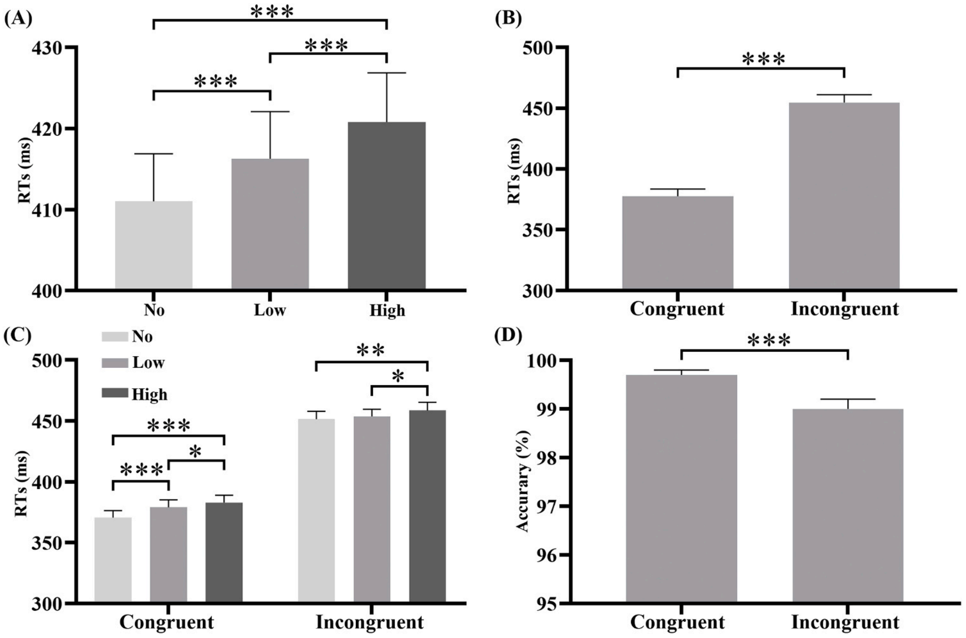

Fig. 2. Bar plots of all significant main and interaction effects in behavioral performance. (A) The main effect of punishment cues on RTs (M±SE). (B) The main effect of congruency on RTs (M±SE). (C) Punishment cue×congruency interaction on RTs (M±SE). (D) The main effect of congruency on accuracy rate (M±SE). $^{*}p < .05$, $^{**}p < .01$, $^{***}p < .001$.

(451.50 ± 6.48 ms) were significantly faster than those in the high-punishment condition (458.61 ± 6.80 ms, $p = .005$). Additionally, RTs in the low-punishment condition (453.62 ± 6.03 ms) were significantly faster than those in the high-punishment condition ($p = .020$) (see Fig. 2C).

3.1.2. Accuracy

The main effect of congruency was significant, $F(1,58)= 20.67$, $p < .001$, $\eta_p^2= .263$. Post hoc multiple comparisons indicated that accuracy rates under incongruent conditions (.990 ±.002) were significantly lower than those under congruent conditions (.997 ±.001) (see Fig. 2D).

3.2. ERP results

3.2.1. Cue-N2

The interaction between test anxiety and punishment cues was significant, $F(2116)= 5.09$, $\varepsilon= .85$, p = .011, $\eta_p^2= .081$. Simple effects analysis revealed that under the high-punishment condition, the HTA group exhibited significantly more negative cue-N2 amplitudes (.29 ±.58 μV) compared to the LTA group (2.53 ±.58 μV, $p = .009$) (see Fig. 3).

3.2.2. Cue-P3

The main effect of test anxiety was significant, $F(1,58)= 4.26$, p = .044, $\eta_p^2= .068$. Post hoc multiple comparisons revealed that the HTA group elicited significantly larger Cue-P3 amplitudes (5.13 ± 0.52 μV) compared to the LTA group (3.62 ± 0.52 μV).

The main effect of punishment cues was significant, $F(2116)= 19.32$, $\varepsilon= .80$, $p < .001$, $\eta_p^2= .250$. Post hoc analyses indicated that the no-punishment condition (3.4 ± 0.40 μV) elicited marginally smaller cue-P3 amplitudes than the low-punishment condition (4.19 ± 0.41 μV, $p = .057$). The no-punishment condition elicited smaller cue-P3 amplitudes than the high-punishment condition (5.47 ± 0.43 μV, $p < .001$). The low-punishment condition elicited smaller cue-P3 amplitudes than the high-punishment condition ($p < .001$) (see Fig. 4).

3.2.3. CNV

The interaction between test anxiety and punishment cues was significant, $F(2116)= 4.15$, $p = .018$, $\eta_p^2= .067$. Simple effects analysis revealed that under the high-punishment condition, the HTA group exhibited significantly more negative CNV amplitudes (-1.17 ± 0.49 μV) compared to the LTA group (0.27 ± 0.49 μV, $p = .041$) (see Fig. 5).

3.2.4. N2

The main effect of congruency was significant, $F(1,58)= 92.51$, $p < .001$, $\eta_p^2= .615$. Post hoc multiple comparisons revealed that incongruent trials elicited significantly more negative N2 amplitudes (-2.71 ± 0.78 μV) compared to congruent trials (2.28 ± 0.67 μV).

The interaction between test anxiety and congruency was significant, $F(1,58)= 4.85$, $p = .032$, $\eta_p^2= .077$. However, simple effects analysis found no significant differences between the HTA group and LTA group under either congruent or incongruent conditions.

The interaction among test anxiety, punishment cues, and congruency was significant, $F(2116)= 3.70$, p = .028, $\eta_p^2= .060$. Simple effects analysis showed that under incongruent trials, the HTA group exhibited

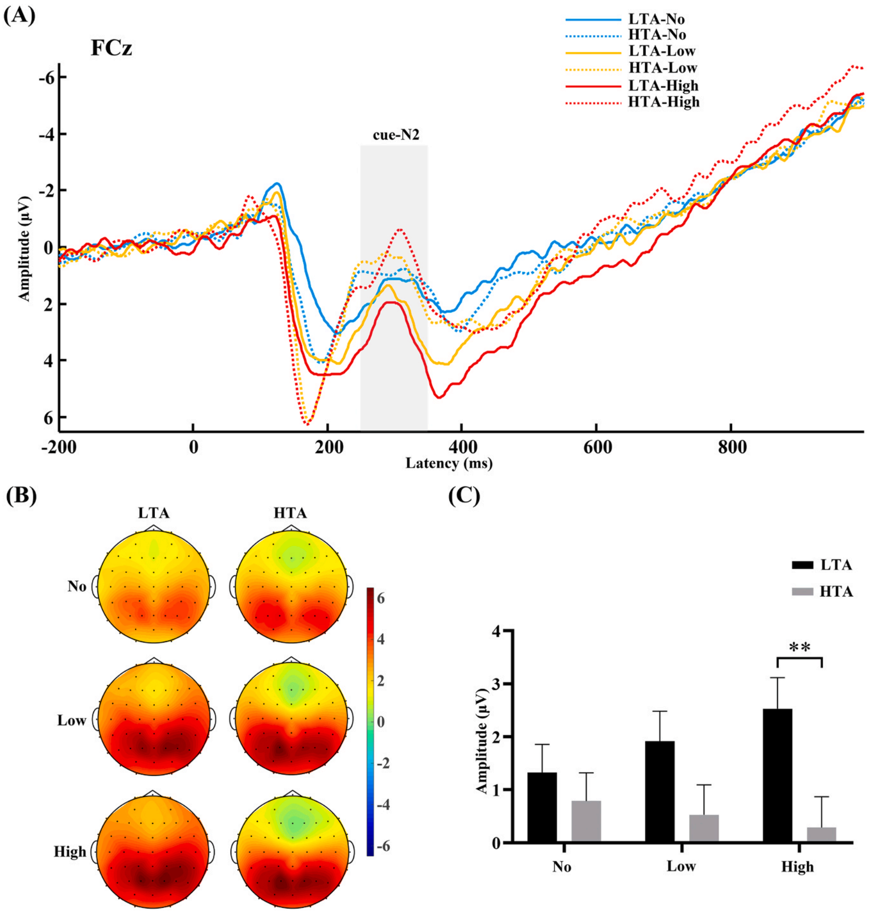

Fig. 3. Mean amplitude results of cue-N2 at electrode FCz. (A) Mean amplitudes of cue-N2 (250–350 ms) for HTA and LTA individuals under no, low, and high punishment conditions, and (B) the corresponding topographic maps. Shaded areas indicated the time windows analyzed. (C) The bar chart (M±SE) shows the average cue-N2 amplitude. **$p < .01$.

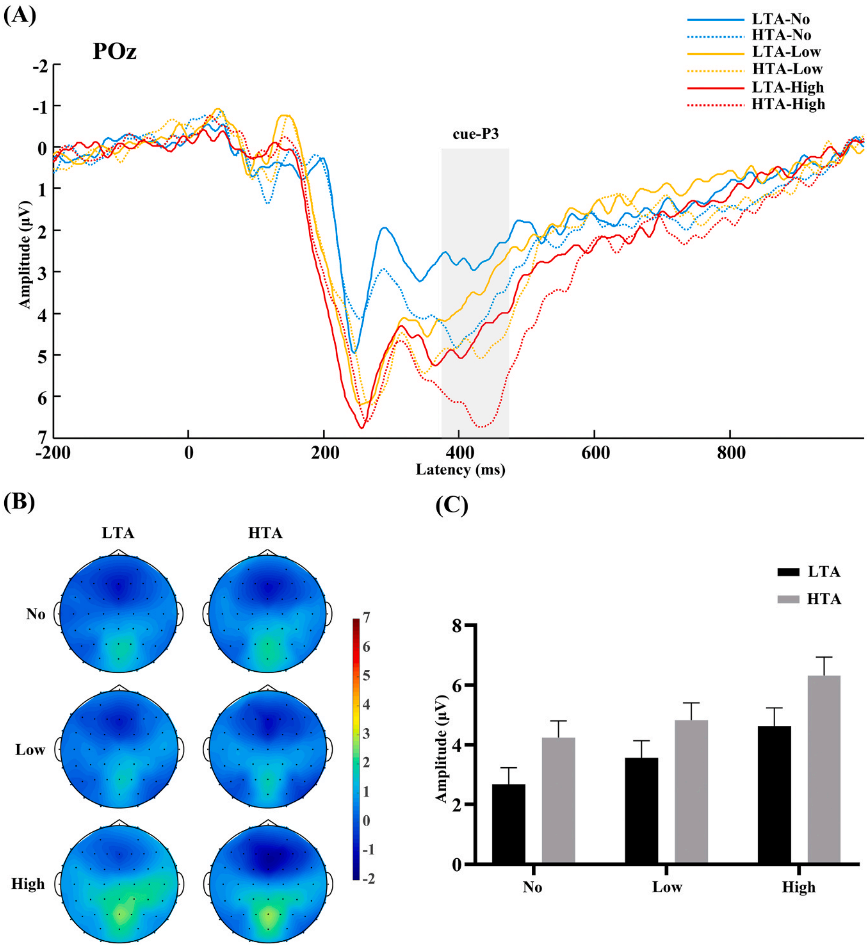

Fig. 4. Mean amplitude results of cue-P3 at electrode POz. (A) Mean cue-P3 amplitudes (370–470 ms) for HTA and LTA individuals under no, low, and high punishment conditions, and (B) the corresponding topographic maps. Shaded areas indicated the time windows analyzed. (C) The bar chart (M±SE) shows the average cue-P3 amplitude. No significant interaction was found.

marginally more negative N2 amplitudes after low-punishment cues (-4.25 ± 1.15 μV) compared to the LTA group (-1.09 ± 1.15 μV, $p = .056$). The HTA group showed significantly more negative N2 amplitudes after high-punishment cues (-4.20 ± 1.17 μV) compared to the LTA group (-0.75 ± 1.17 μV, $p = .042$) (see Fig. 6).

3.2.5. P3

The main effect of test anxiety was significant, $F(1,58)= 4.03$, $p = .049$, $\eta_p^2= .065$. Post hoc comparisons revealed that the HTA group elicited significantly more positive P3 amplitudes (8.12 ± 0.77 μV) compared to the LTA group (5.95 ± 0.77 μV).

The main effect of congruency was significant, $F(1,58)= 15.38$, $p < .001$, $\eta_p^2= .210$. Post hoc analyses indicated that incongruent trials elicited significantly more positive P3 amplitudes (7.84 ± 0.64 μV) compared to congruent trials (6.23 ± 0.51 μV).

The interaction among test anxiety, punishment cues, and congruency was significant, $F(2116)= 4.79$, $\varepsilon= .84$, $p = .015$, $\eta_p^2= .076$. Simple effects analysis showed that under congruent trials, the HTA group exhibited significantly more positive P3 amplitudes (7.76 ± 0.78 μV) following low-punishment cues compared to the LTA group (4.62 ± 0.78 μV, $p = .006$). Under incongruent trials, the HTA group showed significantly more positive P3 amplitudes (9.32 ± 0.93 μV) following no-punishment cues compared to the LTA group (5.89 ± 0.93 μV, $p = .011$) (see Figs. 7A, 7B, 7D, and 7E).

3.2.6. Conflict SP

The main effect of congruency was significant, $F(1,58)= 23.71$, $p < .001$, $\eta_p^2= .290$. Post hoc multiple comparisons revealed that incongruent trials elicited significantly more positive conflict SP amplitudes (2.92 ± 0.55 μV) compared to congruent trials (1.10 ± 0.50 μV).

The interaction among test anxiety, punishment cues, and congruency was significant, $F(2116)= 4.92$, $\varepsilon= .87$, $p = .012$, $\eta_p^2= .078$. Simple effects analysis showed that under incongruent trials, the HTA group exhibited significantly more positive conflict SP amplitudes (4.08 ± 0.85 μV) following no-punishment cues compared to the LTA group (1.49 ± 0.85 μV, $p = .035$) (see Figs. 7A, C, D, and F).

4. Discussion

This study employed the ERP method to investigate the underlying neural mechanisms by which punishment anticipation influences inhibitory control processing in individuals with HTA, through the manipulation of punishment cues. Behavioral results revealed that punishment cues increased RTs in both HTA and LTA individuals. ERP findings indicated that during the cue processing, HTA individuals exhibited more negative cue-N2 and CNV amplitudes under high-punishment conditions compared to LTA individuals. During the inhibitory control processing, N2 amplitudes were enhanced in the high-punishment condition, suggesting increased early conflict monitoring. Both P3 and conflict SP amplitudes were increased in the no-punishment condition, indicating more efficient allocation of cognitive control resources and greater post-conflict processing when punishment pressure was absent. The study demonstrated that punishment anticipation

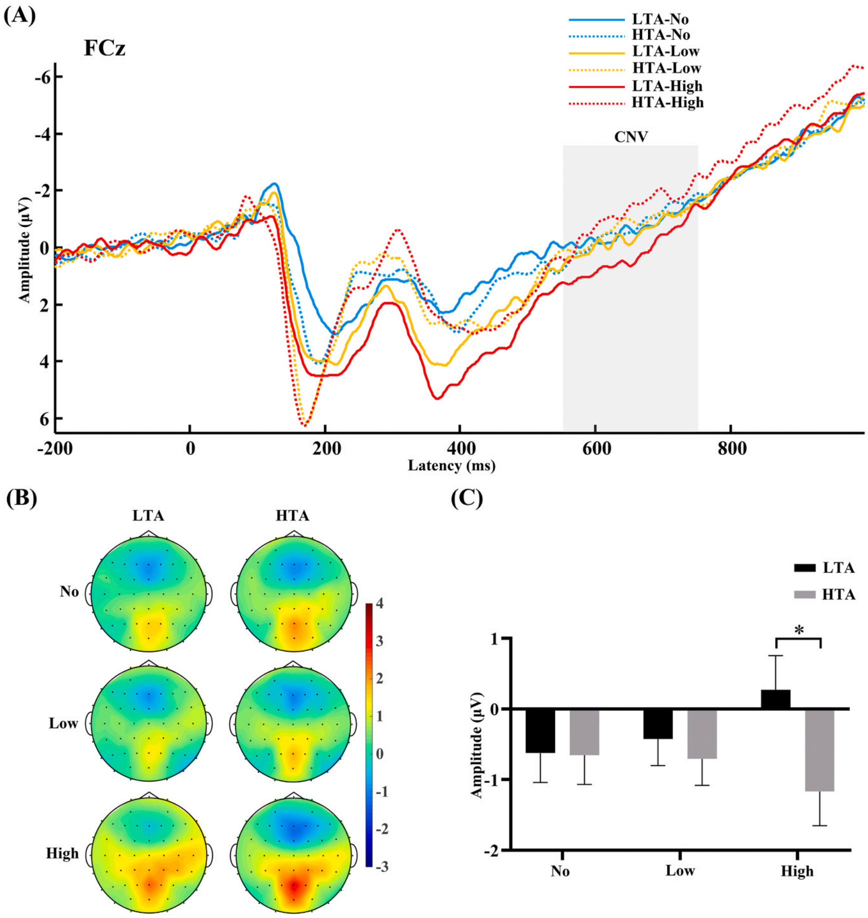

Fig. 5. Mean amplitude results of CNV at electrode FCz. (A) Mean amplitudes of CNV (550–750 ms) for HTA and LTA individuals under no, low, and high punishment conditions, and (B) the corresponding topographic maps. Shaded areas indicated the time windows analyzed. (C) The bar chart (M±SE) shows the average CNV amplitude. *$p < .05$.

modulated inhibitory control processing in individuals with HTA.

No significant group differences were observed in behavioral performance, as both groups achieved near-ceiling accuracy. This suggests that the Flanker task used in the current paradigm may not have been sufficiently challenging to reveal observable behavioral impairments, even under punishment anticipation. The lack of behavioral differences may reflect a dissociation between overt performance and underlying neural processing, with ERP measures capturing more subtle dynamics of cognitive control that are not always detectable in accuracy or reaction time data. Consistent with our findings, prior studies on inhibitory control in test-anxious populations have also rarely reported significant behavioral differences (Wei et al., 2021; Wei et al., 2022). Nevertheless, the present ERP results reveal distinct patterns of neural activity between HTA and LTA individuals during inhibitory control processing.

During the anticipatory phase, we examined ERP components elicited by the cue. This study observed that only under high-punishment conditions did the HTA group elicit more negative cue-N2 amplitudes compared to the LTA group. This aligned with previous research (Novak and Foti, 2015; Potts, 2011; Vignapiano et al., 2018), indicating that cue-N2 exhibited heightened sensitivity to punishment cues. Under high punishment, HTA individuals allocated more attentional resources to task performance, potentially to avoid penalties. According to the template mismatch theory, stronger cognitive responses are elicited when task-related cues deviate from previously learned or expected templates (Brown et al., 2007). In our study, the distinction between no-punishment and low-punishment cues in this study might have been minimal, as low-punishment cues did not substantially deviate from the "template" expectations set by no-punishment cues. In contrast, high-punishment cues induced greater deviation (Zhang et al., 2023), leading to amplified expectation discrepancies perceived by HTA individuals and consequently stronger preparatory states.

The cue-P3 component was associated with subsequent processes of motivational attention and stimulus categorization. The HTA group exhibited significantly larger cue-P3 amplitudes than the LTA group, indicating that the HTA group demonstrated heightened motivational engagement across all cue conditions established in this study (Broyd et al., 2012; Van den Berg et al., 2012). Given the absence of reward conditions and the randomized presentation of different punishment cues across trials, the entire experimental context itself might have been perceived as a punitive situation by HTA individuals, thereby imbuing all cues with substantial motivational salience. This further suggested that HTA individuals exhibited pronounced sensitivity to punishment (Nob, 2013). Additionally, the study observed that cue-P3 amplitudes increased with escalating punishment intensity. This finding aligned with previous studies demonstrating that cue-P3 was highly sensitive to motivationally salient stimulus features (Broyd et al., 2012; Zhang et al., 2023).

The enhanced CNV amplitudes in HTA individuals under high punishment further validated their excessive resource allocation to anticipatory processes. Consistent with the cue-N2 findings, this indicated that high punishment led HTA individuals to excessively allocate resources for preparatory responses to upcoming targets. These results further validated the attentional control theory (Eysenck & Derakshan, 2011), positing that HTA individuals mobilized additional top-down attentional resources to safeguard subsequent processing. Previous studies have shown that higher motivational values (compared to lower

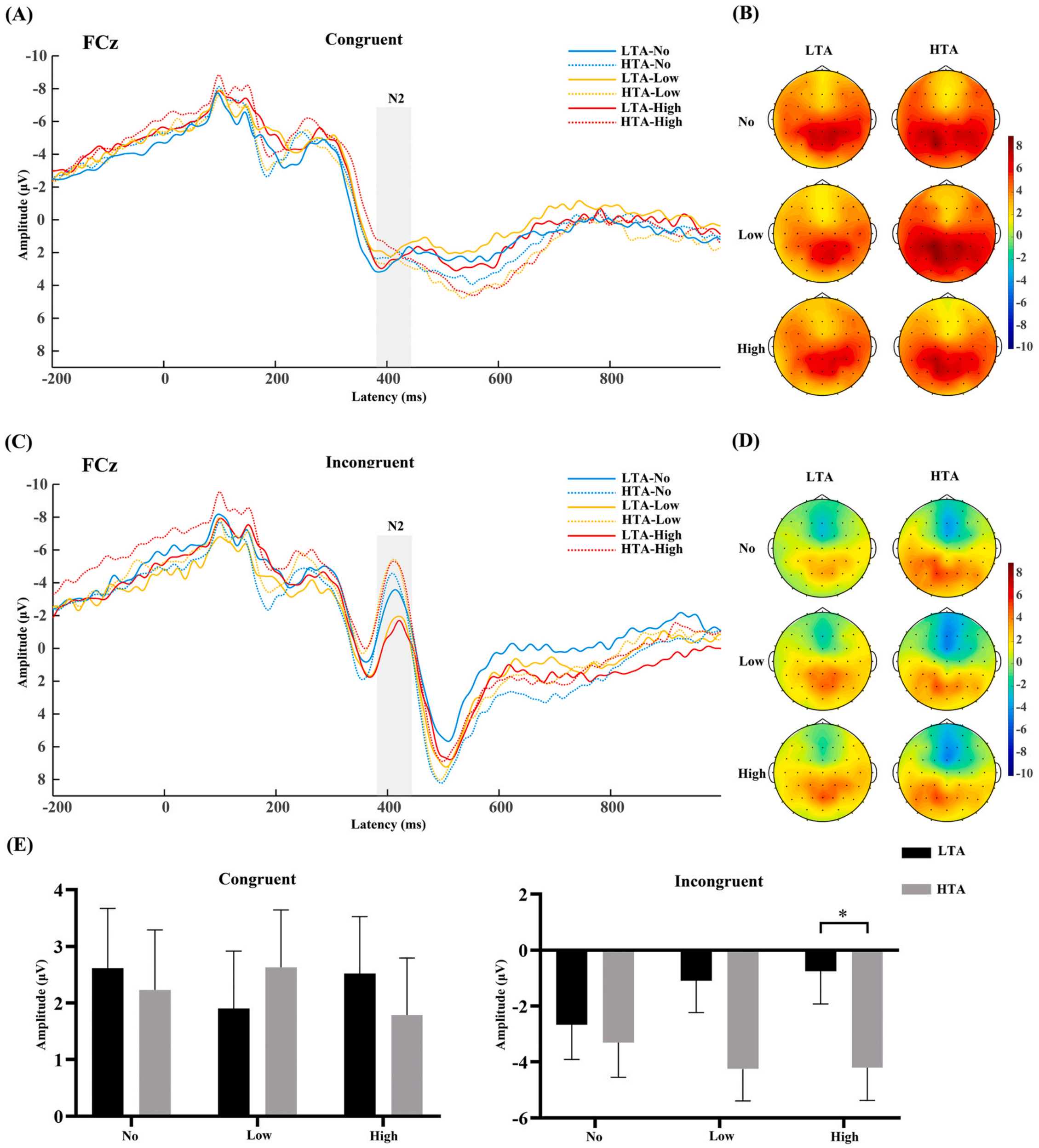

Fig. 6. Mean amplitude results of N2 at electrode FCz. (A) Mean N2 amplitudes (380–440 ms) for HTA and LTA individuals under the congruent condition, and (B) the corresponding topographic maps. (C) Mean N2 amplitudes for the HTA and LTA individuals under the incongruent condition, and (D) the corresponding topographic maps. Shaded areas indicate the analyzed time windows. (E) The bar chart (M±SE) shows the average N2 amplitude under the congruent and incongruent conditions. *$p < .05$.

ones) triggered greater motor preparation for impending targets (Novak and Foti, 2015; Zhang et al., 2023). Increased CNV amplitude has also been associated with tasks perceived as more critical or demanding (Kononowicz and Penney, 2016; Li et al., 2018; Schevernels et al., 2014). Although the difficulty of the inhibitory control task remained constant across punishment conditions, HTA individuals exhibited stronger neural responses under high punishment, suggesting that high punishment may have amplified their subjective perception of task difficulty or threat. This aligned with anxiety-related research demonstrating that HTA individuals tended to underestimate reward value while overestimating punishment value (Miu et al., 2008). Such overestimation of punishment value might cause pre-consumption of cognitive resources, resulting in imbalanced resource allocation during subsequent conflict resolution phases.

Following the cue period, response-related ERPs were analyzed during the inhibitory control processing. This study observed that the attentional resources were directed toward distinct stages of inhibitory control processing. The N2 component reflected conflict monitoring (Kopp et al., 2010; Botvinick et al., 2004). Under incongruent conditions, the N2 amplitudes elicited in HTA individuals following low-punishment cues were marginally more negative than those in the LTA group, and N2 amplitudes following high-punishment cues were significantly more negative in the HTA group. Enhanced N2 amplitudes under high-punishment conditions might indicate that punishment sharpens their perceptual sensitivity to conflict stimuli (Folstein & Van Petten, 2008), albeit at the cost of imposing additional cognitive load. This aligned with prior observations of N2 effects in test contexts (Wei et al., 2022), where HTA individuals recruited greater attentional control resources to maintain task performance parity with low-anxiety counterparts when available resources are not constrained (Eysenck &

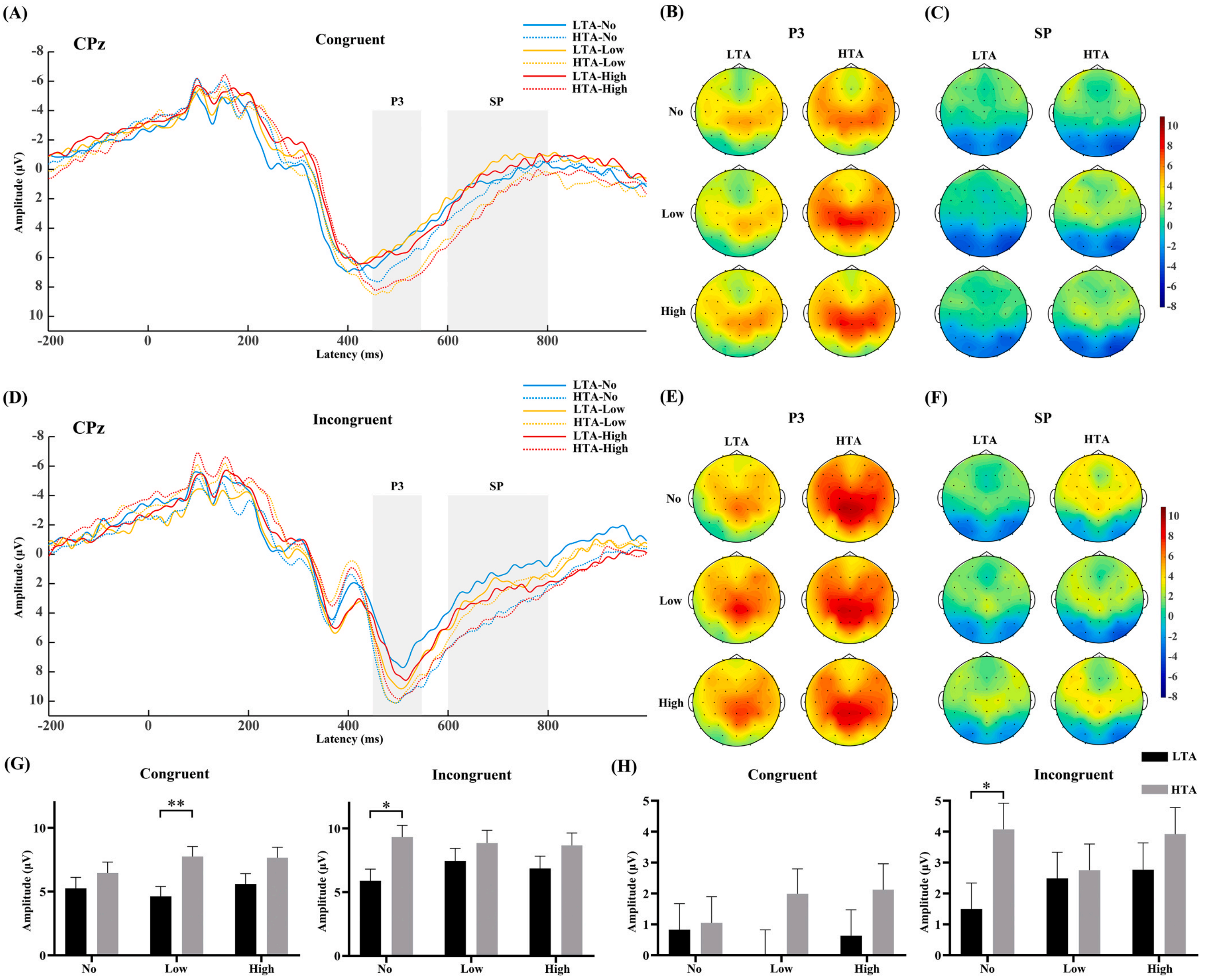

Fig. 7. Mean amplitude results of P3 and conflict SP at electrode CPz. (A) Mean amplitudes of P3 (450–550 ms) and conflict SP (600–800 ms) for HTA and LTA individuals under the congruent condition, along with (B) topographic maps of P3 and (C) conflict SP across conditions. (D) Mean amplitudes of P3 and conflict SP for HTA and LTA individuals under the incongruent condition, with (E) P3 and (F) conflict SP topographic maps. Shaded areas denote the analyzed time windows. The bar chart (M±SE) shows the (G) average P3 amplitude and the (H) average conflict SP amplitude under congruent and incongruent conditions. $^{*}p < .05$, $^{**}p < .01$.

Derakshan, 2011). Similar findings have been reported in anxious individuals, with high-anxiety individuals generating more negative N2 amplitudes compared to those with low anxiety (Owens et al., 2015).

Unlike previous studies on inhibitory control processing in test anxiety, this research observed group differences in P3 amplitudes (related to conflict inhibition) and conflict SP amplitudes (related to conflict resolution) under no-punishment conditions (Chen et al., 2008; Gajewski and Falkenstein, 2013; Groom and Cragg, 2015). In incongruent trials, the HTA group exhibited significantly more positive P3 and conflict SP amplitudes following no-punishment cues compared to the LTA group. Notably, under no-punishment conditions, there was no difference in N2 amplitudes between the HTA and LTA groups. When punishment was absent, HTA individuals allocated attentional control resources to conflict inhibition and resolution. Even in incongruent trials, the HTA group showed more positive P3 amplitudes following low-punishment cues. When punishment levels were low or task difficulty was reduced, HTA individuals appeared to preferentially distribute surplus resources to conflict control.

In conflict adaptation tasks, when both previous and current trials were incongruent, responses to the current incongruent trial accelerated (Koob et al., 2023; Ullsperger et al., 2005). This manifested as reduced activation in the anterior cingulate cortex (ACC) and increased activation in the dorsolateral prefrontal cortex (DLPFC), indicating diminished bottom-up conflict monitoring and enhanced top-down conflict control (Botvinick et al., 2004; Kerns et al., 2004). According to the conflict adaptation effect, enhanced top-down conflict control also contributes more effectively to improving processing efficiency. In the absence of punishment, HTA individuals appear to reallocate control resources toward enhanced conflict resolution. However, when control failures carry punitive consequences, conflict monitoring becomes dominant. The functional integration model of the ACC can explain this phenomenon (Botvinick, 2007). The ACC's response to conflict can also serve as a negative learning signal that participates in and drives avoidance learning. As a negative signal, punishment might amplify ACC activation during conflict monitoring, leading to substantial resource depletion, particularly in punishment-sensitive individuals with HTA.

This study's findings further extended the attentional control theory (Eysenck & Derakshan, 2011). The inhibitory control deficits in individuals with HTA do not solely stem from insufficient cognitive capacity but arise from a dynamic competition for resources triggered by excessive anticipation of punishment for failure consequences. The heightened negative anticipation of punitive outcomes in HTA individuals led to prefrontal overactivation to cope with potential punishment. Early overconsumption of resources may result in insufficient available resources during late-stage inhibitory control. This suggested the need to further understand the mechanisms of test anxiety from the perspective of dynamic interactions between motivational systems and cognitive control systems.

This study has several limitations. First, the experimental design did not include a reward condition, which limits the interpretation of whether the observed neural responses were specific to punishment or reflected a more general sensitivity to motivational salience or value magnitude. Future research incorporating both reward and punishment cues will be necessary to determine whether individuals with HTA exhibit selective reactivity to negative outcomes or heightened sensitivity to motivationally salient information more broadly. Second, the experiment solely manipulated punishment anticipation. Future research could incorporate additional contextual variables (e.g., time pressure or social evaluation) to enhance ecological validity. Third, although our theoretical model proposes that punishment anticipation disrupts inhibitory control via altered cognitive resource allocation, this pathway was not directly tested through statistical mediation or correlational analysis. Future studies should directly examine these relationships using mediation or path analysis approaches to establish causal links between motivational anticipation, cognitive resource allocation, and inhibitory control performance. Fourth, the current study adopted an extreme-groups design, treating test anxiety as a dichotomous variable (HTA vs. LTA). While this approach increases the sensitivity to group differences, it limits the ability to capture individual variability across the full test anxiety spectrum and may reduce generalizability. Future research is encouraged to use continuous modeling of test anxiety with full-range sampling to provide a more nuanced understanding of its impact on cognitive control. Moreover, although the current sample size was comparable to previous ERP studies on test anxiety, it may still limit the statistical power to detect subtle group differences, particularly in complex interaction effects. Therefore, future studies are encouraged to include larger samples to confirm the robustness of these results. Additionally, modulating punishment anticipation might help alleviate the interference of examination contexts on HTA individuals and improve their cognitive performance. Follow-up studies could further mitigate test anxiety by reducing punitive cues in examination scenarios, such as attenuating negative evaluations or diminishing the consequences of failure.

The present study examined the neural correlates associated with punishment anticipation and its relationship to inhibitory control processing in individuals with HTA. The findings revealed that hypersensitivity to punishment anticipation in HTA individuals led to excessive allocation of preparatory resources, resulting in subsequent depletion of inhibitory resources during conflict control processing. By integrating punishment anticipation into the framework of attentional control theory, this research advances the understanding of inhibitory control deficits in test anxiety. Furthermore, it provides novel insights and empirical support for developing interventions that target maladaptive punishment anticipation to improve cognitive functioning in HTA individuals.

CRediT authorship contribution statement

Renlai Zhou: Writing – review & editing, Writing – original draft, Validation, Supervision, Project administration, Funding acquisition, Conceptualization. **Yuhong Ou:** Writing – review & editing, Writing – original draft, Validation, Funding acquisition, Formal analysis, Data curation, Conceptualization.

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

The authors declare that no generative AI or AI-assisted technologies were used in the writing of this manuscript.

Declaration of Competing Interest

I have nothing to declare.

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Data Availability

Data will be made available on request. The datasets generated for this research are available on request to the corresponding author.

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