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Research article

Altered attentional control process of individuals with high test anxiety: An exploratory fMRI study

Lulu Hou [a,b,f], Wenpei Zhang [b,c], Qiong Huang [d], Renlai Zhou [b,e,g,*]

[a] School of Psychology, Shanghai Normal University, Shanghai 200234, China
[b] Department of Psychology, Nanjing University, Nanjing, 210023, China
[c] School of Business, Anhui University of Technology, Maanshan 243032, China
[d] School of Teacher Education, Nanjing Xiaozhuang University, Nanjing 211171, China
[e] Department of Radiology, Nanjing Drum Tower Hospital, the Affiliated Hospital of Nanjing University Medical School, Nanjing 210008, China
[f] Lab for Educational Big Data and Policymaking (Ministry of Education), Shanghai Normal University, Shanghai 200234, China
[g] State Key Laboratory of Media Convergence Production Technology and Systems, Beijing 100803, China

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ABSTRACT

Test anxiety (TA) has been linked to abnormalities in attentional control not only for test-related information but also in situations where irrelevant information has to be ignored. However, the neural basis of individuals with high TA (HTA) when exposed to interference from different types of information remains limited. Twenty-two individuals with HTA and twenty-three individuals with low TA (LTA) completed a Stroop task integrating emotional-word and color-word Stroop tasks. Participants were instructed to assess the font color of neutral words, generally threatening words, test-related threatening words, color-congruent words, and color-incongruent words. Functional magnetic resonance imaging data were recorded simultaneously as the task was completed. The results indicated that compared with LTA group, HTA group exhibited higher activation in the right postcentral gyrus, left cerebellum, right calcarine gyrus, and left inferior parietal lobule when individuals were exposed to interference by test-related threatening words as opposed to neutral words. However, no clusters with significant group-related differences were found when individuals were exposed to interference by generally threatening words and color-incongruent words. These results suggested that differences in attentional control processes between high- and low-test anxiety groups were mainly limited to test-related threatening stimuli and did not extend to generally threatening and cognitively task-irrelevant stimuli.

1. Introduction

Test anxiety is characterized by an excess of apprehension, irrelevant thinking, psychological confusion, tension, and corresponding physiological arousal experienced by an individual facing an examination or evaluation [1,2]. In a sample of English secondary schools, 15–22 % of the students exhibit high test anxiety (HTA) [3]. In China, the severity of test anxiety in college students shows an increasing trend with increasing age, and the incidence of HTA in junior and senior high school students stays around 30 % over the past 15 years [4]. Test anxiety affects academic achievement [5], as well as impairs working memory and attention in students [6,7].

According to attentional control theory [8,9], anxiety leads to an increased allocation of attentional resources toward threatening stimuli. Stated differently, anxiety reduces the effect of goal-directed attention systems but amplifies the effect of stimulus-driven (i.e., test-related threatening stimulus in the current study) attention systems. Extensive research provides evidence for a tendency toward threat-related information in individuals with clinical anxiety as well as those with trait anxiety within the nonpathological range (e.g., [10–14]). Similarly, empirical research suggests that compared with individuals demonstrating low test anxiety (LTA), those with HTA struggle to inhibit their response and are more susceptible to interference from test-related information [1,15–17]. In addition, impairment of attentional control in individuals with HTA extends beyond test-related stimuli. This impairment encompasses all scenarios in which relevant information has to be filtered, whereas irrelevant information should be ignored. Such scenarios include exposure to generally threatening stimuli [15,18,19] as

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* Correspondence to: Department of Psychology, School of Social and Behavioral Science, Nanjing University, Xianlin Avenue 163, Qixia District, Nanjing, Jiangsu Province 210023, China.

E-mail address: rlzhou@nju.edu.cn (R. Zhou).

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well as cognitively distracting or task-irrelevant information [17]. However, previous studies have used accuracy, reaction time, and event-related potential (ERP) components as indicators, ignoring brain activation in individuals with HTA when exposed to interference by various types of information.

On the basis of the aforementioned findings, we used a revised Stroop task combining emotional-word and color-word Stroop tasks, coupled with functional magnetic resonance imaging (fMRI), to investigate the neural responses of individuals with HTA under different interfering stimuli. These stimuli included test-related threatening, generally threatening, and cognitively task-irrelevant information within the same paradigm. The inclusion of three types of stimuli helps to disclose the disorder-specific (i.e., specifically for TA), disorder-general (i.e., like depression and anxiety disorders), and cognitive control characteristics differences of the observed Stroop effect between HTA and LTA groups.

Furthermore, a meta-analysis indicated the activation of the prefrontal cortex (including the dorsolateral prefrontal cortex [dlPFC], inferior frontal gyrus [IFG], and medial prefrontal cortex [mPFC]) and the dorsal anterior cingulate cortex (dACC) when healthy young adults encountered interference from emotion-related information as opposed to neutral stimuli [20]. In cognitive interference, the contrast between incongruent and neutral conditions prompted the activation of a network. This network included right IFG, left dlPFC, bilateral mPFC, left insular cortex, bilateral inferior parietal lobule, and precuneus [21]. Among these brain regions, the dlPFC and ACC have received extensive and enduring research interest despite inconsistent findings (e.g., [11,20]). ACC is responsible for conflict monitoring, and dlPFC is responsible for controlling irrelevant information [11].

In summary, given the limited fMRI research on TA, which primarily focuses on resting-state analyses [22,23], this study adopted a revised Stroop task to investigate the brain activation of individuals with HTA when subjected to test-related threatening stimuli, general threatening stimuli, and cognitively task-irrelevant stimuli. In addition, due to previous studies finding differences in behavioral and ERP indicators between individuals with HTA and LTA when exposed to interference from different types of information [15–19], we tentatively hypothesized that they also exhibit differences in brain activation in the revised Stroop task. These variations are anticipated to manifest primarily in the ACC or dlPFC considering the important role these two brain regions played in the Stroop task. However, based on the inconsistent results reported in individuals with high trait anxiety or patients with generalized anxiety disorder [11,14,24–28], we maintain the exploratory nature of the present study and refrain from formulating specific hypotheses at this point. Finally, due to the strong correlation of TA and depression [29], and the fact that depression can affect individuals' performance in Stroop tasks [30,31], we also measured the severity of depression among participants and included it as a control variable in subsequent analysis.

2. Methods

2.1. Participants

The Test Anxiety Scale (TAS; [32]) described in the subsequent section was used in the present study for sample selection through posters or online advertisements. Participants were further assessed for eligibility based on the following inclusion criteria: right-handedness; absence of color blindness or color weakness; no personal history of diagnosed psychiatric disorders or neurological problems; no use of mood-altering substances in the past 6 months; absence of metals inside the body; no claustrophobia; no cervical spondylosis or tympanitis; no history of self-reported depression treatment, and no severe depression.[1] Notably, with the potential effect of a history of mental disorders on cognitive tasks considered (e.g., [33,34]), the exclusion of participants with a history of psychiatric disorders has become a standard criterion (e.g., [11,35,36]). Thus, we also excluded individuals with a personal history of diagnosed psychiatric disorders.

The desired sample size was determined using G*Power analysis. With a primary focus on the differences between two groups under different interference conditions (i.e., test-related threatening vs. neutral, generally threatening vs. neutral, and incongruent vs. neutral), we selected the following values for the "F-tests> ANOVA: Repeated measures, within-between interaction" (i.e., the interaction effect between Condition and Group here): medium effect size $f = 0.25$, α error probability = .05, power ($1 - \beta$ error probability) = .8, number of groups = 2, number of measurements = 2, correlation among repeat measures = .5, and nonsphericity correct $\in =$ 1 and G*Power recommended a sample size of 17 participants per group. The medium effect size ($f = 0.25$) was selected in this study because the effect sizes of Condition × Group interaction effects ranged from medium to large (η^2 =.10 ~.39) in [17], which used the emotional Stroop task to investigate the differences in ERP components between individuals with HTA and LTA. Finally, among the 172 participants who completed the questionnaire, 25 individuals with HTA and 25 individuals with LTA were included. In the HTA group, 3 participants were excluded, and in the LTA group, 2 participants were excluded from data analysis because of excessive movement (max movement > 2 mm or 2°)[2] during functional scanning.

This study received approval via the Ethical Evaluation of Research Projects at the Department of Psychology in the School for Social and Behavioral Sciences at Nanjing University. All participants provided written informed consent upon arrival at the laboratory. All procedures involving human participants were performed in accordance with the ethical standards of the institutional or national research committee and the 1964 Declaration of Helsinki, together with its later amendments or comparable ethical standards.

2.2. Self-reported questionnaire

In this study, participants were asked to complete Test anxiety scale (TAS), Test anxiety inventory (TAI) and Beck depression inventory (BDI). Among them, TAS was used for sample selection, TAI was used to further confirm the severity levels of TA, and BDI was used to exclude participants with severe depression and as an important covariate in the formal analysis.

2.2.1. Test anxiety scale

Developed by Sarason [32], TAS consisted of 37 true/false items. The total score indicated the extent of test anxiety symptoms experienced. The TAS cutoffs indicate that those with scores exceeding 20 were categorized into the HTA group, whereas those with scores lower than 12 were classified into the LTA group [29]. After the revision of the Chinese version, the test–retest reliability of the scale was .61, and the homogeneity coefficient was .64 [37]. In the study by Wang [37], the reliability coefficient values were not deemed satisfactory when TAS was first introduced in China. Recent studies have demonstrated an improvement in the alpha coefficient, reaching .80 or above (e.g., [38–40]). Moreover, it is widely used for screening participants (e.g., [18,40,41]) because of its fixed cutoffs proposed by Newman— that is, not affected by sample size, unlike other test anxiety scales [42]. In the current study, the Cronbach's alpha coefficient for the scale was .78.

2.2.2. Test anxiety inventory

Introduced by Spielberger [43], TAI consisted of 20 items and 2

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[1] Beck depression inventory scores < 21 indicates no severe depression.

[2] When using the size of one voxel (i.e., max movement > 3 mm or 3°) as the exclusion criterion, three other participants from the HTA group were also included in the analysis, as shown in Table S3 of Supplementary Materials.

subdimensions for worry and emotionality. The statements were rated statements from 1 (never) to 4 (always) on a 4-point scale, indicating the reactions of the participants before, during, and after the test. A higher total score indicated a greater extent of the test anxiety symptoms experienced. After the Chinese version was revised, Cronbach's alpha coefficients for worry, emotionality, and total scale were .90, .80, and .84, respectively [44]. In the current study, Cronbach's alpha coefficients for the two dimensions and the total scale were .91, .89, and .95, respectively.

2.2.3. Beck depression inventory

BDI, which was developed by Beck et al. [45], comprised 21 items rated from 0 (no) to 3 (extremely heavy) on a 4-point scale, indicating the extent to which items reflected the state of the participants. A total score of ≤ 4 reflects no depression or very mild depression; a score of 5–13 reflects mild depression; a score of 14–20 reflects moderate depression; a score of ≥ 21 reflects severe depression. After the Chinese version was revised, Cronbach's alpha was .85, and test–retest reliability was .73 after 1 week [46]. In the present study, Cronbach's alpha for this scale was .92.

2.3. Materials

All words used in the revised Stroop task were two-character Chinese words, which were chosen from the TA vocabulary dataset developed by Gao and Zhou (Table S1 in Supplementary Materials) [18]. This vocabulary dataset including generally threatening (GT) words, test-related threatening (TT) words, and neutral words. All TT words are testing or evaluative situation Chinese college students often encounter in learning, such as "failing a course". All GT words are words related to threats to life, health or dignity, such as "killing". And neutral words are daily supplies that people frequently seen or used, such as "spoon". When compiling this database, three psychology PhDs preliminarily screened the two-character Chinese words and determined 480 words to enter the vocabulary dataset. Then Gao and Zhou [18] asked participants to rate words on the basis of their perceived threatening degree by responding to "How threatening is this word to you [including related unpleasant thoughts and feelings, such as worry or/and anxiety]?"), test-related degree (by responding to "How relevant is this word to "test"), and frequency of usage (by responding to "How often do you use or see this word?") on a 7-point Likert-type scale ranging from 1 (not at all) to 7 (severely threatening/strongly relevant/always, respectively). Words that receive an average participant rating score exceeding 4 on the corresponding dimension are deemed to possess a high level of threatening degree, test-related degree, or frequency of usage. Conversely, words with an average score below 4 on the corresponding dimension are classified as having a low level of threatening degree, test-related degree, or frequency of usage. This dataset has demonstrated high validity in several prior studies conducted among the Chinese university population [17,47,48].

In this study, we selected 15 TT words, 15 GT words and 15 neutral words. All the words were matched as closely as possible in terms of frequency of usage. Among them, TT words exhibited high levels of both threatening degree and test-related degree, whereas GT words displayed high threatening degree but low test-related degree. Neutral words, in contrast, were characterized by low levels of both threatening degree and test-related degree. The results showed significant differences in threatening degree among the three conditions (F [2,42] $= 459.50$, $p < .001$, $\eta_p^2 = .96$, [.92,.97]), with GT (4.60 ± 0.30) and TT (4.55 ± 0.29) conditions exhibiting higher threatening degrees than those of neutral conditions (1.92 ± 0.24) (*Bonferroni ps*[3] <.001). Moreover, significant differences in test-related degree were determined among the three conditions (F [2,42] $= 167.29$, $p < .001$, $\eta_p^2 = .89$, [.81,.92]), with TT (5.03 ± 0.67) conditions exhibiting higher test-related degree than those of GT (2.32 ± 0.31) and neutral (2.87 ± 0.09) conditions (*Bonferroni ps* < .001); moreover, the GT condition showed a higher test-related degree, compared with the neutral condition (*Bonferroni p* = .003). Significant differences in the frequency of usage were noted among the three conditions (F [2,42] $= 4.92$, $p = .01$, $\eta_p^2 = 0.19$, [.01,.36]), with the neutral condition (6.30 ± 0.11) showing a higher frequency of usage than the TT (6.13 ± 0.19) condition (*Bonferroni p* = .01).

2.4. Revised Stroop task

Referring to the previous revised Stroop program [17], participants were asked to respond using their left index finger for red or yellow ink colors and their right index finger for blue or green ink colors while disregarding the meaning of the words. Five conditions were established: (a) neutral words (e.g., refrigerator and plate); (b) GT words (e.g., death and killing); (c) TT words (e.g., test paper and score); (d) color-congruent words (e.g., "RED" in Chinese characters printed in red ink); and (e) color-incongruent (IC) words (e.g., "GREEN'' in Chinese character in red ink).

The revised Stroop program was conducted using a block design, with each condition (i.e., neutral, TT, GT, IC, and congruent conditions) consisting of four blocks presented in a pseudorandomized order. Within each block, 15 nonrepeated words with randomly assigned font colors were randomly presented. Each block began with a fixation point denoted as "+ " on the screen (1000 ms). After a 500 ms blank screen interval, the corresponding words appeared at the center of the screen against a black background (1500 ms). At the end of each trial, a blank screen was displayed at varying time intervals lasting 300–500 ms. Therefore, the duration of each block ranged from 28.5–31.5 s. At the end of each block, the participants rested for 20 s before proceeding to the subsequent block.

2.5. FMRI recording

A 3-T Siemens Trio MRI scanner (Siemens Medical Erlangen, Germany) was used to collect all images, including high-resolution T1-weighted brain structure images acquired using a magnetization-prepared rapid gradient echo sequence (TR = 2600 ms; TE = 3.02 ms; flip angle = 8°; matrix size = 256 × 256; 176 slices; 1.00 mm slice thickness; voxel size = 1 mm × 1 mm × 1 mm) and T2*-weighted images recorded using an echo-planar imaging sequence (TR = 2000 ms; TE = 30 ms; flip angle = 90°; field of view = 240 mm × 240 mm; matrix size = 64 × 64; 33 interleaved 3 mm thick slices; in-plane resolution = 3.4 mm × 3.4 mm; interslice skip = 1 mm; volume = 243 per run).

2.6. Data analysis

Initially, we conduct Shapiro–Wilk test to assess the normality of data. If the results of the Shapiro–Wilk test are not statistically significant, it indicates that the data follows a normal distribution, thereby permitting the use of parametric tests. Conversely, significant results from the Shapiro–Wilk test indicate a deviation from normality, requiring the application of nonparametric testing methods. Specifically, we performed Mann-Whitney U test to evaluate potential differences in demographic variables and questionnaire scores between the two groups due to the significant Shapiro–Wilk test results (*ps* < .05). For reaction time in the Stroop task, we conducted three mixed two-way analysis of variance (ANOVA) with one between-subjects factor Group (HTA vs. LTA) and one within-subjects factor Condition (neutral words vs. TT words/GT words/IC words) due to the nonsignificant Shapiro–Wilk test results (*ps* > .08). Furthermore, due to the significant Shapiro–Wilk test results (*ps* < .05), the response accuracy was analyzed nonparametrically. The Mann-Whitney U tests were employed to examine differences between groups across all conditions (i.e., the main

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[3] We used *Bonferroni p* and *Bonferroni ps* as abbreviations for single and multiple p-values corrected by Bonferroni multiple comparisons, respectively.

effect of Group), while the Wilcoxon test were used to assess differences among conditions (i.e., the main effect of Condition). Additionally, we calculated the three interference effects by subtracting the accuracy of neutral words from the accuracy of TT, GT, and IC words. To assess differences in these interference effects between groups, we employed the Mann-Whitney *U* tests, which allowed us to determine the interaction effects between Group and Condition. According to [49], effect sizes were quantified using r and η_p^2 for the nonparametric test and ANOVAs, respectively. Data were statistically analyzed using SPSS 22.0 (IBM Corp., Armonk, NY, USA). According to [50], the cutoff values of r for small, medium, and large levels are 0.10, 0.30, and 0.50, respectively. Furthermore, Ferguson (2009) proposed that the cutoff values of η_p^2 for small, medium, and large levels in the field of social sciences are 0.04, 0.25, and 0.64, respectively [51]. It should be noted that due to limitations in the nonparametric test function of the software, we did not include covariates in the behavioral data analysis.

To analyze the fMRI data, we used the Data Processing Assistant for Resting-State fMRI toolbox ([52]; http://restfmri.net/forum/DPARSF). The preprocessing steps were as follows: (1) Conversion of raw DICOM data into the NIFTI data format; (2) Correction of time series to the middle time point throughout the whole brain scan for differences in slice acquisition times; (3) Reorientation of all volumes with respect to the first volume. Participants with head translation exceeding 2.0 mm or head rotation exceeding 2° were excluded, and no significant difference in average head movement was found between the two groups (FD_Power parameter[4]: 0.10 ± 0.03 vs. 0.12 ± 0.05, $z = 1.12$, $p = .26$); (4) Co-registration of structural images to the mean functional image, followed by segmentation into gray matter, white matter, and cerebrospinal fluid via the new segment method; (5) Normalization of each functional image to the standard Montreal Neurological Institute (MNI) space via DARTEL (diffeomorphic anatomical registration through exponentiated Lie algebra); and (6) After normalization, spatial smoothing with a 4 mm full-width at half-maximum Gaussian kernel. It should be noted that the head movement exclusion criteria and selections of smooth kernel vary across studies. For example, Oren et al. used 2 mm/2° [54], Verdolini et al. used a stricter standard of 0.3 mm/0.3° [55], while Hong et al. (2024) used a looser standard of framewise displacement exceeding 0.5 (the maximum of head movement is 0.28 in our study) [56]. Considering the exploratory nature and limited sample size of this study, we have chosen a moderate level of head movement exclusion criteria and included the results of more lenient criteria in the Table S3 of Supplementary Materials. Furthermore, Liu et al. [57] found that smaller smooth kernels not exceeding two voxel sizes can effectively reduce false positive rates and potential overestimation of the cluster size. According to our data, due to the voxel size was 3 mm× 3.4 mm × 3.4 mm, 4 mm or 6 mm are acceptable. Furthermore, due to the use of a 4 mm smoothing kernel in data processing during the development of the fMRI version of the color word Stroop [58], we also chose a 4 mm smoothing kernel.

Then, we used SPM12 (https://www.fil.ion.ucl.ac.uk/spm) to do further statistical analysis. Low-frequency noise was removed by applying a high-pass filter (a cutoff of 128 s) to the fMRI time series at each voxel and modelling temporal autocorrelation across scans with an autoregressive AR (1) model. For each condition, significant hemodynamic changes were determined using the general linear model. The event-related response convolved with a canonical hemodynamic response function was considered. First-level effects were modelled by convolving an event-related hemodynamic response function and its temporal derivative against pre-processed data for each of the 6 conditions (rest, neutral words, TT words, GT words, congruent words, and IC words) and 6 motion regressors (3 dimensions of linear and rotated displacement, respectively). The contrast values for TT words vs. neutral words, GT words vs. neutral words, congruent words vs. neutral words, IC words vs. neutral words, and IC words vs. congruent words were then extracted. At the second level, one-sample *t*-tests and independent sample *t*-tests were conducted to assess the effects of interference and the differences between the two groups.

Notably, sex and average head movement parameters (i.e., FD_Power) were used as covariates in the independent sample *t*-tests to more optimally exclude the influence of head movement and unmatched sex ratio. The BDI score was also used as a covariate to exclude the influence of depression. This choice was attributed to the average BDI score of the HTA group exhibiting moderate depression and depression was associated with performance in Stroop task [30,31]. In addition, age was not included as a covariate in the model. This exclusion was prompted by the group differences in age resulting from smaller standard deviations and a narrow age range of whole samples. The results of covariates for other combinations (Model 1: sex and FD, Model 2: sex, FD, and age; Model 3: sex, FD, age, and BDI score) are listed in Tables S4-S6 of Supplementary Materials. Statistical maps were estimated using a gray matter mask. The results of all one-sample and independent *t*-tests of congruent words vs. neutral words and IC words vs. congruent words are shown in Tables S7-S11 of Supplementary Materials. Only the group-related effects of three types of interference effects (GT vs. neutral words, TT vs. neutral words, and IC words vs. neutral words) are included in the main text. Regarding the fMRI analysis, considering that the power to detect between-subject effects is typically much lower than the power to detect within-subject effects [59,60] and referring to [11], we set the voxel-level statistical threshold at $p < .001$ and $p < .005$ and corrected it with a cluster level of $p < .05$ at the familywise error (FWE) for one sample and independent sample *t*-tests, respectively.

3. Results

3.1. Demographic variables and questionnaires

Significant differences in age, sex ratio, and the scores of each questionnaire exist between the two groups ($ps < .05$) (Table 1).

3.2. Behavioral data results

3.2.1. Accuracy

For all conditions, there was no significant differences between HTA and LTA groups ($ps < .25$). For both groups, there was no significant differences neither between neutral and TT words ($p = .09$), nor between neutral and GT words ($p = .43$). As a comparison, there was significant difference between neutral and IC words ($p = .001$). Furthermore, for TT and GT interference effect, there was no significant differences between

Table 1
Demographic variables and questionnaire scores in the two groups ($M \pm SD$).

	HTA group ($n = 22$)	LTA group ($n = 23$)	z/χ^2	r
Female (n)	16	9	5.14*	—
Age (years)	21.23 ± 2.25	22.91 ± 1.98	2.50*	0.37
TAS	25.09 ± 3.29	8.00 ± 2.50	−5.76***	−0.85
TAI-W	17.00 ± 4.03	8.87 ± 1.25	−5.84***	−0.87
TAI-E	24.73 ± 4.47	13.17 ± 1.83	−5.76***	−0.85
TAI	44.73 ± 8.11	24.13 ± 3.09	−5.76***	−0.86
BDI	15.36 ± 9.93	3.65 ± 5.36	−4.35***	−0.65

Note: TAS: Test Anxiety Scale; TAI-W: Test Anxiety Inventory – Worry; TAI-E: Test Anxiety Inventory – Emotionality; TAI: Test Anxiety Inventory; BDI: Beck depression inventory;

* $p < .05$,

*** $p < .001$.

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[4] It refers to the mean framewise displacement computed by summing the absolute values of the derivatives of the translational and rotational realignment estimates (after converting rotational estimates to displacement at 50 mm radius), as Power et al. [53] did.

HTA and LTA groups ($ps > .10$). On contrast, there was significant group difference between HTA and LTA groups in the IC interference effect ($p = .02$). Further analysis found that there was no significant difference in accuracy between IC and neutral words in the HTA group ($p = .21$), while the accuracy of IC words was lower than that of neutral words in the LTA group ($p = .001$).

3.2.2. Reaction time

The main effects of Condition and Group, as well as the Condition × Group interaction effects for the interference effects of TT and GT words, were not significant (TT words: all F [1,43] < 1.46, $p > .23$; GT words: all F [1,43] < 1.39, $p > .25$). With regard to the interference effect of IC words, the main effect of Condition was significant, with shorter reaction times for neutral words than for IC words (F [1,43] $=$ 38.56, $p < .001$, $\eta_p^2 = .47$, [.25,.62]). However, the Group main effect and the Condition × Group interaction effect were not significant (all F [1, 43] < 3.09, $p > .09$).

The mean accuracy and reaction time for each condition in each group, together with the statistical values of the behavioral data results, are presented in Table 2 and Table S2 in Supplementary Materials, respectively.

3.3. FMRI data results

Activation in the right postcentral gyrus ([39 –33 57], $k = 165$, $T = 4.20$, p [*FWE correction*] $< .001$, Fig. 1a), left cerebellum ([–12 –57 −18], $k = 98$, $T = 4.37$, p [*FWE correction*] $= .008$, Fig. 1b), right calcarine gyrus (24 –48 −3, $k = 83$, $T = 4.90$, p [*FWE correction*] $= .02$, Fig. 1c), and left inferior parietal lobule ([–45 –33 42], $k = 71$, $T = 4.30$, p [*FWE correction*] $= .04$, Fig. 1d) was higher in the HTA group than in the LTA group when exposed to interference by TT words (Table 3). No significant differences were found between the two groups exposed to interference by GT and IC words.

4. Discussion

This study used a revised Stroop task to investigate brain activation linked to attentional control in individuals with HTA who are exposed to interference from different types of words simultaneously. Behavioral results indicated that the LTA group exhibited lower accuracy under the IC condition than under the neutral condition; this trend was not observed in the HTA group. The fMRI results revealed that when exposed to TT word interference, the HTA group exhibited higher activation in the right postcentral gyrus, left cerebellum, right calcarine gyrus, and left inferior parietal lobule. No significant differences were found between the two groups exposed to interference by GT and IC words.

Among the significant clusters, the inferior parietal lobule, an important region in the executive control network (ECN, also known as the frontoparietal network) [61], has been observed in emotional Stroop tasks [62]. Healthy individuals with high anxious apprehension scores [63] and patients with panic disorder [64] require higher activation of the inferior parietal lobules to successfully execute emotional Stroop tasks than healthy controls. Moreover, a meta-analysis by Feng et al. (2018) [62] suggests that hyperactivation in the prefrontal and parietal regions is a trans-diagnostic pattern. This pattern may reflect an excessive engagement of cognitive control networks to regulate the effect of emotional distractors. Therefore, when participants in the HTA group experienced interference by TT words, the enhanced activation of the inferior parietal lobule may also indicate their attempt to increase attentional control over test-related threats. It is important to note that when a more lenient standard for head movement exclusion was applied, the group-related differences in the left inferior parietal lobule diminished (see Table S3). This may be attributed to the attention control difficulties faced by individuals exhibiting excessive head movements. Anyway, caution should be exercised when drawing conclusions from these findings.

Moreover, the postcentral gyrus is responsible for sensory information input [65]. Previous meta-analysis [20] and empirical research [66, 67] on healthy participants have observed activation in the postcentral gyrus during the emotional Stroop task. Compared with those in the control group, individuals with social anxiety disorder exhibit higher activation in the postcentral gyrus [68]. Cerebellar injury may lead to dyskinesia [69], as well as complex cognitive, behavioral, and emotional symptoms [70,71]. Research involving healthy groups has also revealed the involvement of the cerebellum in emotional processes [72]. Located in the occipital pole, the calcarine cortex serves as a primary visual region [73]. Previous studies have demonstrated the role of the calcarine cortex in processing emotional visual stimuli, with increased activation observed in the visual cortical regions in the presence of emotional stimuli [74]. The enhanced activation of brain regions in the sensorimotor network (including the postcentral gyrus and cerebellum) and visual network (i.e., the calcarine cortex) were in line with findings by [22] that the resting-state functional connectivity between the ECN and sensorimotor and visual networks was lower in the HTA group than in the LTA group. These findings suggest that exaggerated recruitment of sensorimotor and visual networks is crucial to ensure that task performance is not compromised due to the reduced functional coupling between ECN and sensorimotor and visual networks. In summary, when exposed to interference by TT words, participants in the HTA group exhibited increased activation in the attentional control network (mainly the inferior parietal lobules) to achieved attentional control over threatening stimuli. Furthermore, they also improved task performance by exaggerated recruitment of the sensorimotor (including the postcentral gyrus and cerebellum) and visual networks (the calcarine cortex), which were essential for the successful execution of the emotional Stroop task. Considering the link between neural activation and behavioral indicators, there was a significant trend between neural activation in the right calcarine gyrus and the RT of the TT interference effect ($r = .36$, $p = .097$) as well as neural activation in the left cerebellum and the accuracy of the TT interference effect ($r = -.38$, $p = .077$). However, due to the small sample size, no significant correlation result was obtained between neural activation and behavioral indicators. Therefore, the explanation should be cautious when draw conclusions.

Brain activation levels between groups varied when participants were exposed to interference by IC and GT words. However, these differences disappeared when BDI scores as covariates were included and age as a covariate was excluded (Tables S4–S6 in Supplementary Materials). Comparing Table 3 and Table S4, as well as Table S5 and Table S6, we could find the severity of depression mainly associated with the group-related differences on the interference effect of GT, which was indicated in the left superior orbitofrontal gyrus extended to left caudate. Put it differently, the differences between HTA and LTA group in the interference effect of GT was actually induced by their differences on depression. Therefore, the influence of depression on the interference effect of GT was not only manifested in populations with depression [75] but also showed in those with TA. Furthermore, when

Table 2
Accuracy and reaction time for four conditions in two groups ($M \pm SD$).

	HTA group ($n = 22$)	LTA group ($n = 23$)
Accuracy		
Neutral words	0.94 ± 0.07	0.96 ± 0.04
Test-related threatening words	0.94 ± 0.07	0.94 ± 0.05
Generally threatening words	0.94 ± 0.06	0.94 ± 0.07
Incongruent words	0.92 ± 0.07	0.90 ± 0.08
Reaction Time (ms)		
Neutral words	679.82 ± 80.20	716.87 ± 100.27
Test-related threatening words	681.73 ± 67.88	704.52 ± 89.63
Generally threatening words	690.50 ± 78.19	712.00 ± 90.64
Incongruent words	728.86 ± 79.80	785.26 ± 112.62

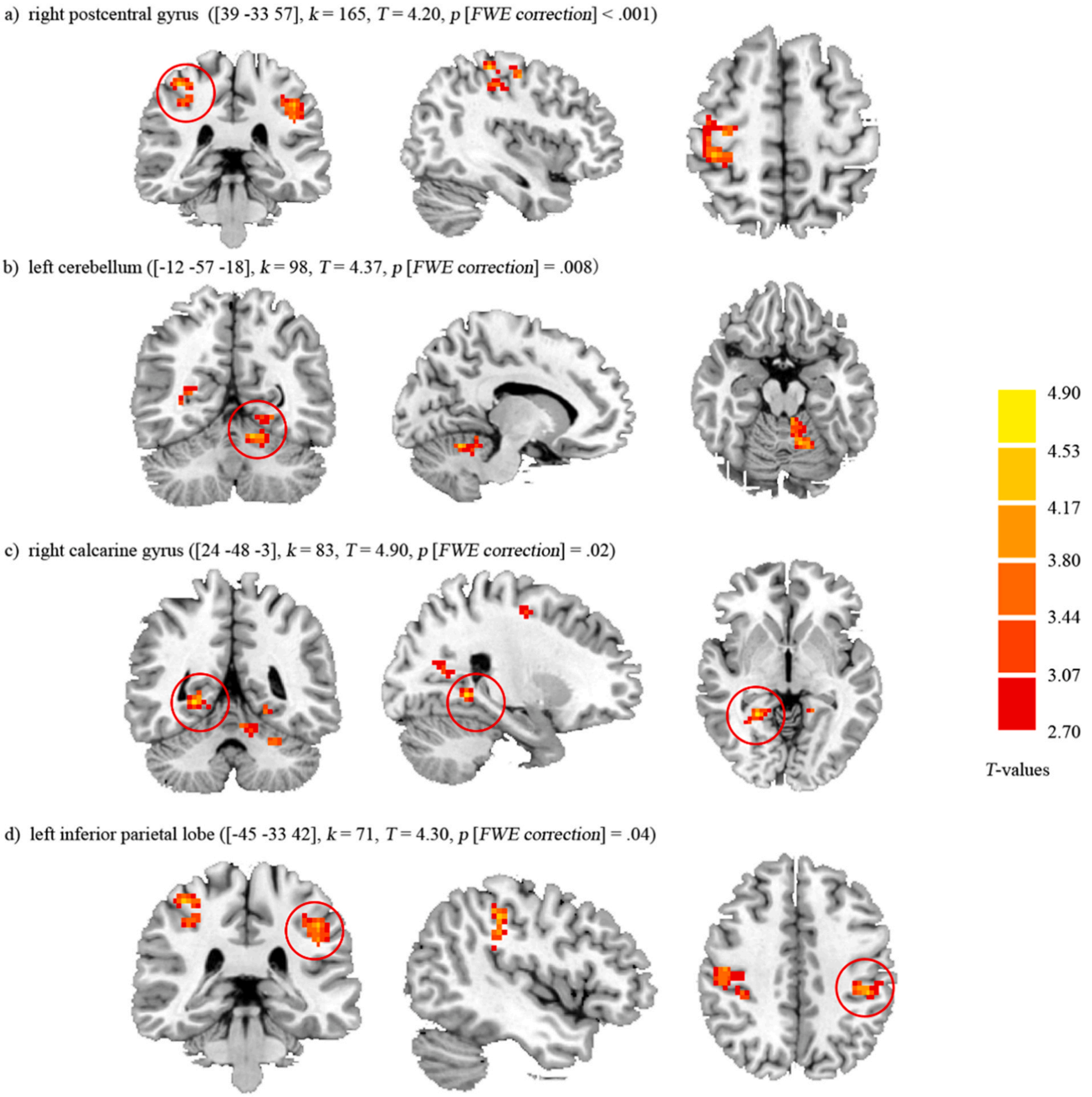

Fig. 1. Compared with the LTA group, the HTA group exhibited higher activation in the (**a**) right postcentral gyrus, (b) left cerebellum, (c) right calcarine gyrus, and (d) left inferior parietal lobule when they were exposed to interference by test-related threatening words.

comparing Table 3 and Table S6 as well as Table S4 and Table S5, we could find age mainly associated with the group-related differences on the interference effect of IC. The group-related differences appeared when age was included as a covariate but disappeared when age was excluded as a covariate. It seems that age and TA influence the interference effect of IC together. However, due to the rarity of this pattern in previous studies, it will not be explained in detail. In summary, TA impact on the interference effect of TT words stable, but on the interference effect of GT and IC words unstable. Our results are different from the previous results using behavioral and ERP indicators [15,17–19], which may be due to the control of more covariates in this study. As an example, the group-related differences in HTA and LTA in the face of GT words interference mainly caused by differences in depression levels between the two groups. Therefore, the results of this study could better explain the situational-trait characteristics of TA while controlling for depression levels. Put it differently, the attention control deficits observed in individuals with TA in previous studies may stem from other traits possessed by the individuals themselves rather than being caused by the test anxiety itself. Of course, due to the exploratory nature of this study and the limitations of the small sample size, further investigation and verification are needed in the future. Moreover, significant interaction effects were observed in accuracy when participants experienced interference by IC. This observation may be attributed to the HTA group's ability to allocate greater cognitive resources to the task or to the beneficial effects of heightened engagement of cognitive control networks in regulating emotional distractors (i.e., TT words) on IC regulation. Alternatively, it is possible that individuals with HTA exhibit reduced sensitivity to cognitive interference due to an increased sensitivity to TT interference.

In summary, this study investigates the brain activation of individuals with HTA when confronted with various types of interfering stimuli for the first time, thus advancing our understanding of the neural mechanisms that underlie TA. From a practical perspective, our findings indicate that individuals with HTA tend to overreact to exam-related threats. This suggests the need to refocus on the role of scores in education as a means of providing constructive feedback, rather than

Table 3
Group differences for different interference effects.

Cluster-level sig.	Voxels	*T*	MNI			Region
			X	Y	Z	
HTA > LTA and Test-related threatening > Neutral:						
< .001	165	4.20	39	−33	57	Right postcentral extended to right precentral gyrus
		3.99	48	−18	42	
		3.95	33	−21	57	
.008	98	4.37	−12	−57	−18	Left cerebellum
		3.91	−6	−39	−18	
		3.91	−27	−51	−27	
.02	83	4.90	24	−48	−3	Right calcarine gyrus extended to right lingual gyrus and precentral gyrus
		3.86	18	−69	15	
		3.54	33	−54	6	
.04	71	4.30	−45	−33	42	Left inferior parietal lobule extended to left postcentral gyrus
		4.13	−45	−33	33	
		3.82	−51	−39	24	
LTA > HTA and Generally threatening > Neutral:						
None.						
HTA > LTA and Incongruent > Neutral:						
None.						

Note: The voxel-level statistical threshold was set at $p < .005$, corrected with a cluster-level of $p < .05$ at the family-wise error (FWE).

excessively emphasizing their significance in terms of rankings. Additionally, for individuals who have already developed HTA, we should adopt some intervention methods, such as cognitive-behavioral therapy to change their unreasonable belifes of exams or mindfulness cognitive therapy to further enhance their attention control ability. In addition, due to the exploratory nature of this study, there are still many unresolved issues that require further research in the future. For example, firstly, this study only revealed the brain activation, while previous studies have found abnormalities in resting state functional connectivity in individuals with TA. Therefore, in the future, further investigation should be conducted to determine whether the coupling between different brain regions in individuals with HTA is different from that in individuals with LTA when facing different types of interfering stimuli. Secondly, the current study adopted a cross-sectional experimental design, preventing causal inferences. Thus, in the future, longitudinal designs should be further adopted to verify the causal relationship between TA and attention control. Finally, in the future, more intervention studies should be conducted to examine the effect of cognitive-behavioral therapy or mindfulness cognitive therapy.

This study has several limitations that require further improvement. First, despite efforts to match word frequency for each condition and demographic variables in each group, the frequency of word usage and the age and sex ratio of the participants exhibited a mismatch. In future research, better-matched participants and stimulus materials should be used to validate the research results. Second, in compiling the test anxiety vocabulary dataset, Gao and Zhou [18] only considered participant ratings on threatening degree, test-related degree, and frequency of usage, disregarding the complexity and concreteness of words. These dimensions should be re-evaluated during the experiment in future studies. Third, while repetitive stimuli have been used in previous research such as that by [25] the use of nonrepetitive stimuli in future research might be more beneficial. Fourth, the current study involved college students, and the generalization of relevant conclusions to primary and secondary school students with a larger proportion of examinations needs further investigation.

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

CRediT authorship contribution statement

Zhou Renlai: Writing – review & editing, Validation, Supervision, Project administration, Methodology, Investigation, Funding acquisition, Conceptualization. **Huang Qiong:** Formal analysis, Data curation. **Zhang Wenpei:** Formal analysis, Data curation. **Hou Lulu:** Writing – review & editing, Writing – original draft, Visualization, Validation, Formal analysis, Conceptualization.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.bbr.2025.115486.

Data availability

The data supporting the findings of this study are available from the corresponding author upon reasonable request, subject to the completion of a formal data-sharing agreement.

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