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Emotional Stroop performance in adults and children with test anxiety: An ERP study

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ABSTRACT

Test anxiety significantly impacts the cognitive performance of both children and adults, yet its specific effects on cognitive processing in response to test-related threatening stimuli across various age groups remain to be fully elucidated. This study employed the emotional Stroop task alongside ERP technology to explore the cognitive processing differences in response to threatening stimuli between children ($n = 48$) and adults ($n = 55$) categorized into high and low test anxiety groups. The findings indicated that children, compared to adults, demonstrated reduced accuracy and extended response times in the emotional Stroop task, along with increased ERP amplitudes. Notably, among children with low test anxiety, the N450 amplitude was significantly less negative under the threatening condition compared to the neutral condition. These results contribute to the foundational understanding of the cognitive-neural underpinnings of test anxiety.

1. Introduction

Test anxiety refers to the physiological and behavioral responses exhibited by individuals in evaluative situations, accompanied by concerns about potential negative outcomes or failure (Zeidner, 1998). It is a specific form of anxiety where individuals prone to test anxiety perceive evaluative situations, such as exams, as threatening and experience persistent high anxiety states (Spielberger, 1995). In the UK, 16.4 % of secondary school students report experiencing highly test anxiety (Putwain and Daly, 2014), and over 25 % of college students report experiencing most symptoms of test anxiety "often" or more frequently (Lovett et al., 2024). High test anxiety not only negatively predicts students' subjective well-being (Steinmayr et al., 2016), but also impairs their executive functioning and academic performance (Wei et al., 2022). Test anxiety has been identified as a significant predictor of increased stress and anxiety. Students with higher levels of test anxiety, particularly during examination periods, experience greater emotional distress (Wuthrich et al., 2021). A meta-analysis study shows that test anxiety is negatively correlated with academic performance in mathematics and literacy, academic self-concept, and self-efficacy, and positively correlated with general anxiety, social anxiety, and depression (Robson et al., 2023).

According to Spielberger's Transactional Theory of Test Anxiety, test anxiety arises from the interaction between students and the situational factor of exams (Spielberger, 1995). Therefore, the importance of exams in the educational context of students at different age levels is a significant factor influencing the prevalence of test anxiety. In China, both children and adults suffer extensively from test anxiety. As early as fourth grade, the incidence of high test anxiety among Chinese children reaches 32.3 %, and over a span of 15 years, the rate of high test anxiety among Chinese university students increased by 13.2 percentage points (Huang and Zhou, 2019). Children are at a critical stage of cognitive and emotional development, with their brains and emotional regulation abilities maturing (Fischer and Bullock, 1984). Therefore, we aim to examine whether there are differences between children and adults in processing test-related information. In China's educational system, college students also face intense exam pressure (with exam scores still being a crucial factor influencing job selection), positioning this age group at the tail end of the high incidence period for test anxiety (Huang and Zhou, 2019). Thus, college students represent an adult exception with a high incidence of test anxiety. In this study, we selected 10–12-year-old children who are just beginning to take more challenging academic exams and 19–24-year-old college students as participants.

Anxiety evolves throughout childhood, and emerging evidence

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suggests a potential causal relationship between the cognitive processing of threats in both adults and children and the development and maintenance of anxiety (Burris et al., 2019). From a young age, children demonstrate an ability to rapidly detect various threats, paralleling adult capabilities (LoBue, 2013). In China, where an exam-oriented education system predominates, the unequal distribution of educational resources and a scarcity of high-quality options render examinations the principal competitive arena for students from early childhood through early adulthood (Huang and Zhou, 2019). Negative experiences associated with exams can influence the cognitive processing of test-related threatening stimuli in individuals experiencing test anxiety. Such individuals exhibit not only a generalized attentional bias towards threatening stimuli (Putwain et al., 2020) but also a specific bias towards test-related threats (Hu et al., 2022) and show deficits in inhibitory control over such stimuli (Zhang et al., 2019). Variations in cognitive development, emotional regulation, and neural system maturity between anxious children and adults may result in divergent neural responses when engaging with threatening tasks (Gold et al., 2020). The substantial differences in developmental trajectories and exam experiences between children and adults could lead to distinct patterns of cognitive processing of test-related threats. Despite this, research in this domain has predominantly centered on adults, with comparative studies between these demographic groups remaining limited.

The emotional Stroop task measures individuals' cognitive processing of threatening information by requiring participants to identify the ink color of threatening (or emotional) and neutral words (Williams et al., 1996). According to the facilitation of attention theory, individuals tend to notice threatening stimuli more quickly, and this focused attention often comes at the expense of other stimulus attributes, such as the recognition of ink color, indicating that threatening stimuli can preferentially attract an individual's attentional resources (Williams et al., 1996). On the other hand, the difficulty of disengagement theory posits that once attention is allocated to a threatening stimulus, it lingers longer on that stimulus, thereby delaying the processing of non-threatening stimulus attributes (Fox et al., 2001). Both theories underscore the importance of threat perception in attention allocation and provide theoretical support for the suitability of the emotional Stroop task in measuring cognitive processing (Suárez-Pellicioni et al., 2015). Individuals with high trait anxiety and clinical anxiety tend to interpret ambiguous information from the environment as threatening (Beck and Clark, 1988). Therefore, for individuals with test anxiety, words related to exams are more likely to be perceived as threats, and the emotional Stroop paradigm employed in this study uses test-related words as threatening conditions (Zhang et al., 2019).

Compared to merely inferring attentional biases towards threatening words based on reaction times, event-related potentials (ERPs) offer a more direct method to study cognitive-related brain activity. Therefore, in the emotional Stroop task, ERPs are ideal due to their high temporal resolution and direct measurement capabilities, allowing for the precise capture and analysis of cognitive processes in individuals with test anxiety (Thomas et al., 2007), reflecting the automatic draw of attention triggered by the emotional load of words (Imbir et al., 2021). Two sensitive negative waves typically appear in cognitive control tasks: the earlier N2 component, related to the initial detection of conflict, and the mid-latency N450, which involves more sustained cognitive control processes necessary for conflict resolution (Folstein and Van Petten, 2008). These components are crucial for understanding the neural dynamics of cognitive control and conflict processing in the context of test anxiety. In the emotional Stroop task, the N2 responds to early emotional and cognitive aspects of threat stimuli, reflecting activity related to automatic attention based on stimulus features (Thomas et al., 2007), while the N450 is associated with later cognitive control (Imbir et al., 2021), involving the sustained cognitive control processes required to resolve conflicts between emotional content and task demands (Guo et al., 2018). Currently, in exploring the effects of test anxiety, we know little about the neural activity patterns in the emotional Stroop task across different age groups, which limits our understanding of the neural mechanisms by which attentional biases induced by test anxiety occur at different developmental stages. This study aims to directly compare the behavioral and neural activity differences between children and adults with high and low test anxiety through the measurement of N2 and N450 event-related potentials. We hypothesize that children, due to their developmental stage, will exhibit greater ERP amplitudes and poorer behavioral performance compared to adults. Additionally, we hypothesize that children with high test anxiety will exhibit more negative N2 and N450 responses to test-related threat stimuli compared to children with low test anxiety, indicating more pronounced cognitive and emotional interference.

2. Methods

2.1. Participants

In this study, we conducted a priori power analysis using G*Power3.1to determine the required sample size. We planned to use a 2 (Age: children vs. adults) x 2 (Group: high test anxiety vs. low test anxiety) x 2 (Condition: threatening vs. neutral) experimental design, where Age and Group were between-subject factors, and Condition was a within-subject factor. To detect three-way interaction effects in the experiment, we selected a medium effect size of 0.25 according to Cohen's (1988) standards, with an alpha level of 0.05 and a power of 0.95. Based on this, a total of 76 participants was required for the experiment. 141 adults from a university and 118 children from a primary school signed up for participating in the experiments, and 55 adults (28 males, aged 19–24) and 48 children (24 males, aged 10–12) got eventually selected for participation in the study. In accordance with Newman (Newman, 1996), those participants (both adults and children) scoring >20 on TAS (test anxiety scale) were assigned to high test anxiety (HTA) groups (28 adults, 21 children); while those participants scoring <12 on TAS were assigned to low test anxiety (LTA) groups (27 adults, 27 children). 86 adults and 70 children were excluded because (a) they were neither HTA nor LTA, and/or (b) they appeared to have suffered or still suffer from currently known psychiatric disorders (e.g., depression, bipolar disorder, and substance abuse) as diagnosed (just before the start of this study) by a self-completed Structured Clinical Interview for DSM-IV (First and Gibbon, 2004), and/or (c) they reported a history of epilepsy, brain trauma, or other neurological disorders during verbal screening, and/or (d) they did not have normal or corrected-to-normal vision, or were not right-handed. The average TAS score for high test anxiety children was 24.81 (SD = 3.17), while for high test anxiety adults, the average score was 23.79 (SD = 4.69). Children with low test anxiety had an average TAS score of 7.74 (SD = 2.75), and the adults with low test anxiety had an average TAS score of 9.37 (SD = 2.19). To control for the impact of trait anxiety, State-Trait Anxiety Inventory-Trait (STAI-T, Spielberger et al., 1971) scores were collected across four groups, revealing no significant differences, $F(3, 99) = 0.759$, $p = 0.520$.

2.2. Stimuli and procedures

The emotional Stroop task requires participants to name the color of words displayed on a screen, while disregarding their semantic meaning (Zhang et al., 2019). The colors of the words include four conditions: red, yellow, green, and blue. The words presented in the experiment are selected from the test-related word database compiled by Zhang (2017). This database comprises 1046 words, each rated for its level of threat, relevance to testing, and frequency of usage. We select 12 words from the database for each condition. The semantic meaning of the words falls into two categories: test-related threat words (e.g., "exam", "challenging questions") and neutral words (e.g., "village", "goose"). A significant difference exists in relevance scores ($t(22) = 21.150$, $p < 0.001$) and threat scores ($t(22) = 21.164$, $p < 0.001$) between the two categories. No significant difference is found in the frequency between the two categories ($t(22) = 1.203, p = 0.253$. Each word is presented twice under each color condition, totaling 192 trials. The words are presented in random order during the task. Regarding the word length, both the threatening and neutral words consist of two Chinese characters. Each trial begins with a fixation point '+' displayed on the computer screen, which remains for 200 ms. Following this, the fixation point disappears, and there is a randomly selected inter-stimulus interval lasting between 800 and 1200 ms. Subsequently, the word is displayed at the center of a black screen. Each trial ends either when the participant responds (i.e., presses a button to indicate the color of the word) or if no response is made within 2000 ms. The task is administered using e-Prime software (Version 3.0, Psychology Software Tools, Inc., Sharpsburg, USA). After a brief rest upon arriving at the laboratory, participants undertake the emotional Stroop task, during which their brain electrical activity is simultaneously recorded.

2.3. EEG recording, preprocessing and ERP analysis

EEG data for both adults and children were recorded by Grael EEG amplifier and Curry8–32 channel system. The reference point for EEG recordings was located at the midpoint between FPz and Fz. The data sampling rate was set to 1024 Hz, and the impedance of all electrodes was maintained below 10 kΩ throughout the experimental procedure. Following data collection, the EEG data were preprocessed using MATLAB-based EEGLAB toolbox. The EEG signals were subjected to a 30 Hz low-pass filter and a 0.1 Hz high-pass filter, and were re-referenced to the average of M1 and M2. Additionally, the continuous EEG data were segmented from −200 ms to 1000 ms around the stimulus presentation, and ocular artifacts were removed through independent component analysis (ICA). Only correct trials were included in the final analysis. Trials with amplitude values exceeding ±80 μV at any electrode were rejected. No participants were excluded due to poor quality data. EEG epochs were segmented into 1200-ms time windows, including a 200-ms prestimulus baseline and 1000 ms poststimulus period, and were baseline-corrected using the prestimulus interval. The number of trials used for ERP analysis in each condition was as follows: in the HTA children group, the threatening condition had an average of 78.62 trials (SD = 6.48), and the neutral condition had 78.52 trials (SD = 6.80); in the LTA children group, the threatening condition had 80.92 trials (SD = 9.33), and the neutral condition had 78.14 trials (SD = 11.61); in the HTA adults group, the threatening condition had 89.79 trials (SD = 4.63), and the neutral condition had 89.14 trials (SD = 4.87); in the LTA adults group, the threatening condition had 87.07 trials (SD = 7.14), and the neutral condition had 87.07 trials (SD = 7.91). The time windows for quantifying the ERPs were defined in two steps. First, regions of interest were selected based on ERP components identified in previous studies. Second, the exact time windows for each ERP component were determined by calculating the average latency from the stimulus onset to the peak for each condition and group. The electrodes for analysis were determined based on the topographical maps. For children/adults, the average voltage at the frontal electrode (Fz) during the 290–370 ms/260–340 ms post-stimulus interval was measured to assess the stimulus-related N2 amplitude (Thomas et al., 2007), and the stimulus-related N450 amplitude was measured based on the average voltage at the frontal electrode (Fz) during the 400–490 ms interval (Zhao et al., 2015).

2.4. Statistical analysis

Data were analyzed using a mixed analysis of variance (ANOVA) with SPSS (version 26) for Windows (IBM SPSS Inc., USA). Descriptive statistics are presented as mean ± SD (standard deviation). Statistical significance was set at $p < 0.05$. The final .sav data file has been uploaded to OSF (https://osf.io/wah9b/).

3. Results

3.1. Behavioral performance

Descriptive statistics are presented in Table 1. A three-way mixed analysis of variance (ANOVA) was conducted on participants' accuracy and response times, with 2 (Age: children vs. adults) x 2 (Group: high test anxiety vs. low test anxiety) x 2 (Condition: threatening vs. neutral) factors, where Age and Group were between-subject factors, and Condition was a within-subject factor. For accuracy, the main effect of Age was significant, $F(1,99) = 42.025, p < 0.001, \eta_p^2 = 0.298$; the main effect of Group was not significant, $F(1,99) = 0.034, p = 0.851, \eta_p^2 < 0.001$; the main effect of Condition was not significant, $F(1,99) = 0.721, p = 0.398, \eta_p^2 = 0.007$. The interaction between Age and Group was not significant, $F(1,99) = 0.405, p = 0.526, \eta_p^2 = 0.004$; the interaction between Age and Condition was not significant, $F(1,99) = 0.362, p = 0.549, \eta_p^2 = 0.004$; the interaction between Group and Condition was not significant, $F(1,99) = 0.024, p = 0.877, \eta_p^2 < 0.001$; the three-way interaction was not significant, $F(1,99) = 0.62, p = 0.433, \eta_p^2 = 0.006$.

Only correctly responded trials were included in the analysis of response times. For response times, the main effect of Age was significant, $F(1,99) = 68.411, p < 0.001, \eta_p^2 = 0.409$; the main effect of Group was not significant, $F(1,99) = 3.527, p = 0.063, \eta_p^2 = 0.034$; the main effect of Condition was not significant, $F(1,99) = 1.472, p = 0.228, \eta_p^2 = 0.015$. The interaction between Age and Group was not significant, $F(1,99) = 0.003, p = 0.955, \eta_p^2 < 0.001$; the interaction between Age and Condition was not significant, $F(1,99) = 1.597, p = 0.209, \eta_p^2 = 0.016$; the interaction between Group and Condition was not significant, $F(1,99) = 0.592, p = 0.444, \eta_p^2 = 0.006$; the three-way interaction was not significant, $F(1,99) = 1.418, p = 0.237, \eta_p^2 = 0.014$. Overall, children exhibited lower accuracy and slower response times compared to adults.

3.2. ERP results

Topographical maps are shown in Fig. 1. ERP waveforms at the frontal electrode Fz are shown in Fig. 2A. A three-way mixed ANOVA with factors of Age (children vs. adults), Group (high test anxiety vs. low test anxiety), and Condition (threatening vs. neutral) was conducted to statistically test the amplitudes of N2 and N450 (see Fig. 2B).

For N2, the main effect of Age was significant, $F(1,99) = 14.439, p < 0.001, \eta_p^2 = 0.127$; the main effect of Group was not significant, $F(1,99) = 0.112, p = 0.738, \eta_p^2 = 0.001$; the main effect of Condition was not significant, $F(1,99) = 1.856, p = 0.176, \eta_p^2 = 0.018$; no significant interactions were observed between Age and Group, $F(1,99) = 0.008, p = 0.93, \eta_p^2 < 0.001$, between Age and Condition, $F(1,99) = 1.339, p = 0.25, \eta_p^2 = 0.013$, or between Group and Condition, $F(1,99) = 3.097, p = 0.082, \eta_p^2 = 0.03$; the three-way interaction was not significant, $F(1,99) = 1.874, p = 0.174, \eta_p^2 = 0.019$.

For N450, the main effect of Age was significant, $F(1,99) = 43.671, p < 0.001, \eta_p^2 = 0.303$; the main effect of Group was not significant, $F(1,99) = 0.623, p = 0.432, \eta_p^2 = 0.006$; the main effect of Condition was significant, $F(1,99) = 6.041, p = 0.016, \eta_p^2 = 0.06$; no significant interactions were observed between Age and Group, $F(1,99) = 0.008, p = 0.928, \eta_p^2 < 0.001$, or between Age and Condition, $F(1,99) = 0.102, p = 0.75, \eta_p^2 = 0.001$, or between Group and Condition, $F(1,99) = 3.026, p = 0.085, \eta_p^2 = 0.03$. The three-way interaction was significant, $F(1,99) = 4.342, p = 0.04, \eta_p^2 = 0.042$. Further simple effects analysis was conducted to examine the group differences within each condition and the condition differences within each group. In the threatening condition, no significant differences were found between LTA and HTA children, $F(1,99) = 1.714, p = 0.193, \eta_p^2 = 0.017$, nor between LTA and HTA adults, $F(1,99) = 0.183, p = 0.67, \eta_p^2 = 0.002$. Similarly, in the neutral condition, there were no significant differences between LTA and HTA children, $F(1,99) = 0.02, p = 0.887, \eta_p^2 < 0.001$, or between LTA and HTA adults, $F(1,99) = 0.311, p = 0.578, \eta_p^2 = 0.003$. When comparing the threatening and neutral conditions within each group, no significant

Table 1
Descriptive statistics of behavioral performance (mean ± SD).

	HTA Children ($n = 21$)	LTA Children ($n = 27$)	HTA Adults ($n = 28$)	LTA Adults (n = 27)
Threatening Condition Accuracy (%)	84.38 ± 11.41	85.30 ± 10.67	96.11 ± 4.34	95.67 ± 5.10
Neutral Condition Accuracy (%)	83.81 ± 13.13	85.63 ± 11.55	95.71 ± 4.28	94.67 ± 5.75
Threatening Condition Correct RTs (ms)	583.49 ± 195.02	514.62 ± 178.20	345.35 ± 122.37	296.04 ± 112.86
Neutral Condition Correct RTs (ms)	587.04 ± 176.78	545.04 ± 169.17	347.89 ± 120.68	320.85 ± 115.42

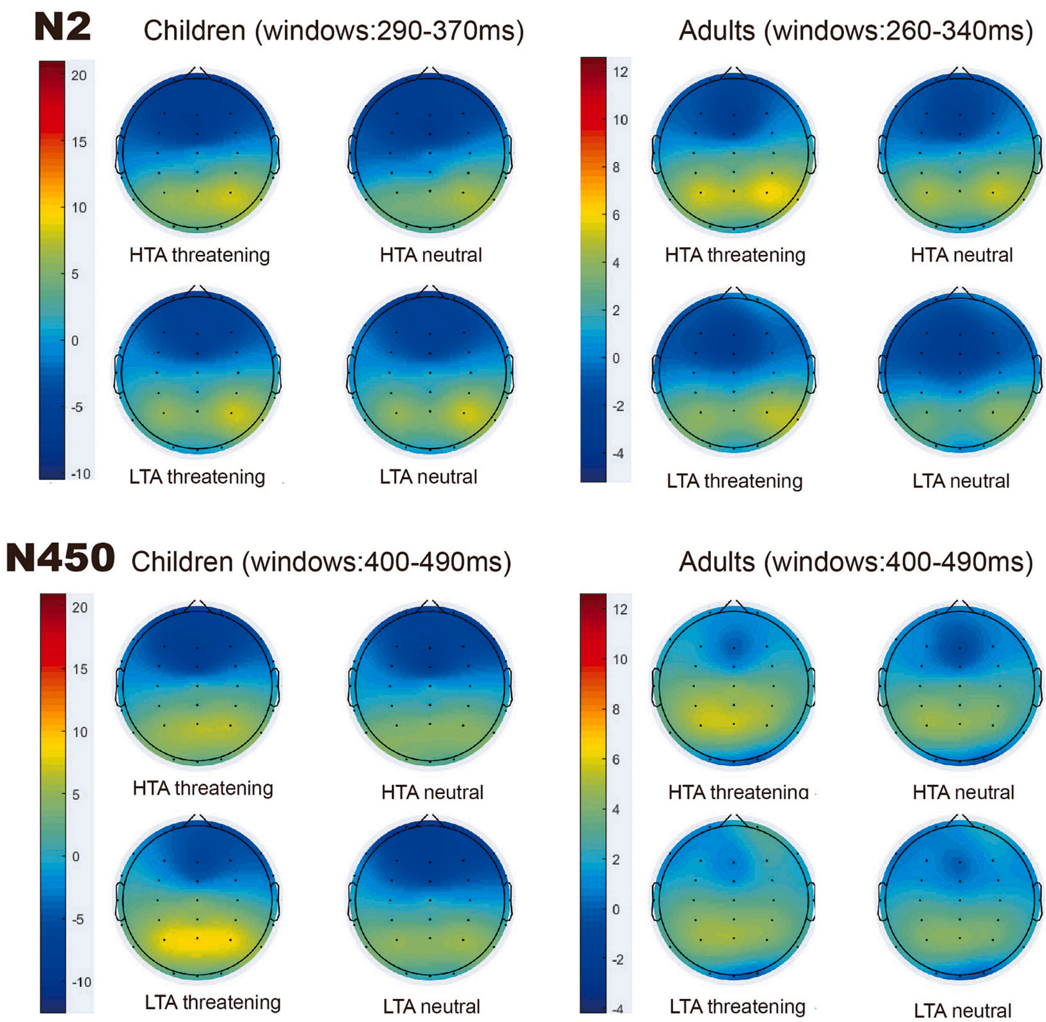

Fig. 1. Topographical maps of N2 and N450 components for children and adults in threatening and neutral conditions.

differences were observed for HTA children, $F(1,99) = 0.226$, $p = 0.636$, $\eta_p^2 = 0.002$, HTA adults, $F(1,99) = 1.698$, $p = 0.196$, $\eta_p^2 = 0.017$, or LTA adults, $F(1,99) = 0.855$, $p = 0.357$, $\eta_p^2 = 0.009$. Only in the LTA children group was a significant difference found between the threatening and neutral conditions, $F(1,99) = 11.573$, $p = 0.001$, $\eta p^2 = 0.105$.

4. Discussion

This study examined how test anxiety affects attentional biases in children and adults and utilized ERPs to explore the potential impacts of test anxiety on cognitive and emotional processing from a developmental perspective. In terms of behavioral performance, children showed lower accuracy and longer response times, reflecting greater difficulties in task processing compared to adults, regardless of anxiety levels. In ERP results, children exhibited larger (more negative) N2 and N450 amplitudes, suggesting that they may require more neural resources to complete tasks. Despite this, the larger overall ERP amplitudes in children did not significantly correspond to improved cognitive performance (behavioral outcomes), which could be due to ongoing cognitive function and brain development. This finding is consistent with previous developmental studies on the Stroop task (Wright, 2017).

Moreover, we observed significant differences in the N450 amplitudes under threatening compared to neutral conditions exclusively in children with low test anxiety. This result indicated that our hypothesis was not confirmed across the studied sample. Research suggests that when words possess stronger subjective meaning, the N450 amplitudes are more positive (Imbir et al., 2021). Subjective meaning, as part of emotional experience, is influenced by reflective processes that evaluate the personal significance of a stimulus, akin to how arousal is triggered by immediate sensory impacts (Imbir, 2016). Thus, the ERP responses observed in children with lower levels of test anxiety might indicate that exams can evoke considerable cognitive processing, regardless of the

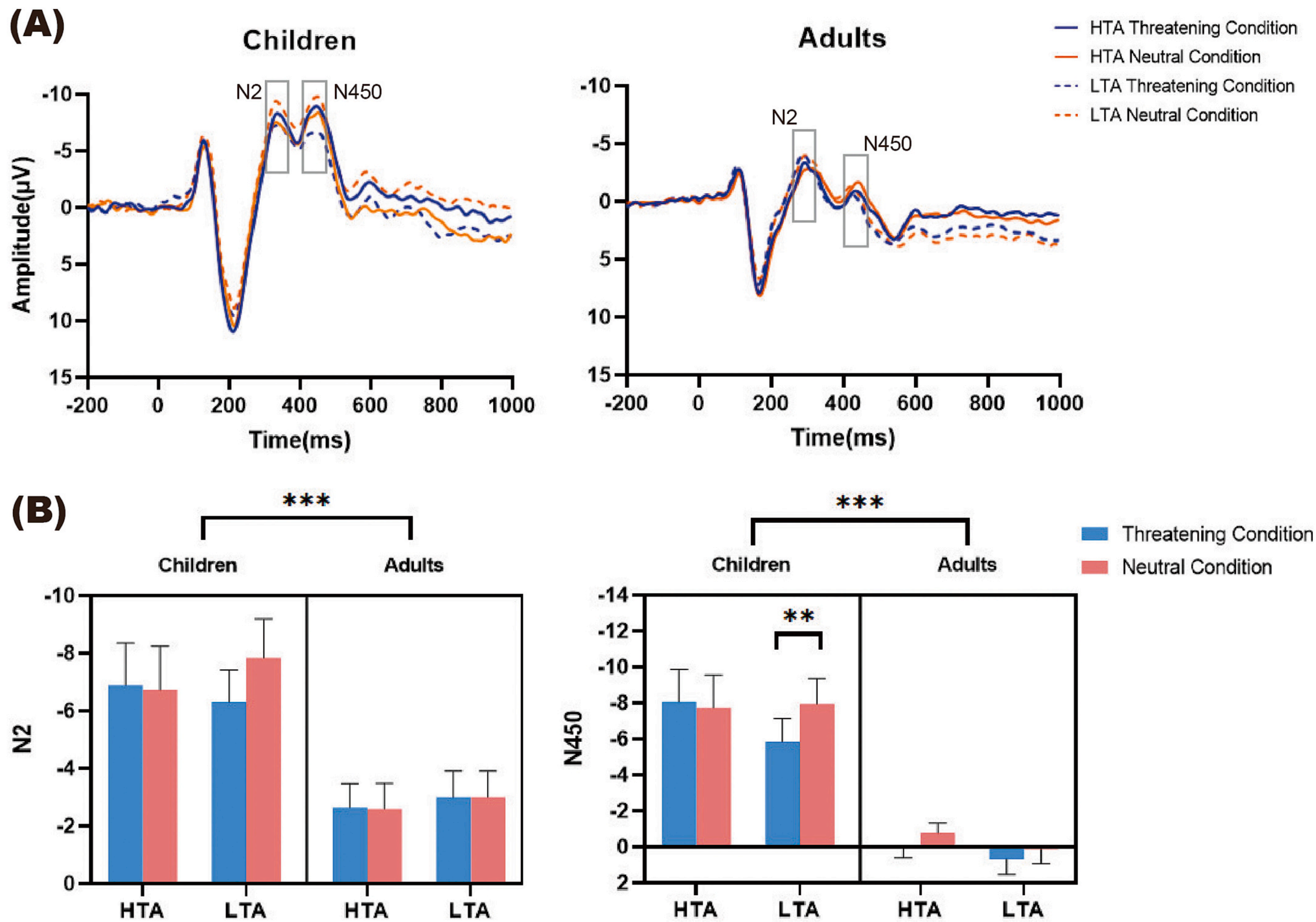

Fig. 2. (A) Waveforms at the Fz electrode during the Stroop task for children and adults with high and low test anxiety. (B) Differences in N2 and N450 amplitudes between children and adults with high and low test anxiety. The error bars represent standard errors of the mean (SEM).$^{**}p < 0.01$, $^{***}p < 0.001$.

reported anxiety levels. The absence of ERP differences between threatening and neutral conditions in children with high test anxiety could be explained by these children adopting avoidance strategies towards exam-related threatening stimuli. The Model of Coping Modes suggests that there are two coping strategies when facing threatening information: vigilance, where the individual seeks information to reduce uncertainty and prevent surprises, and cognitive avoidance, where the individual reduces anxiety by avoiding negative stimuli, with those prone to anxiety tending to use cognitive avoidance strategies (Günther et al., 2023). Studies show that avoidance emotion regulation strategies are a significant factor in explaining anxiety in children and adolescents (Kraft et al., 2023), and this experiential avoidance refers to the avoidance of negative emotions, thoughts, and memories (Hayes et al., 1996). Research on the intergenerational transmission of anxiety further suggests that anxious children may learn fears and avoidance responses to potential threats from their parents (Aktar et al., 2017). Therefore, children with high test anxiety might display avoidance towards negative exam experiences when faced with exam-related threat stimuli, manifesting as non-significant N450 amplitudes across the two conditions of the emotional Stroop task. Conversely, children with low test anxiety showed a response to threat words, indicating their greater sensitivity to such threatening information, possibly because they employ vigilance strategies and experience anxiety less frequently, thus maintaining higher sensitivity to such stimuli.

For adults, exams are no longer the sole means of assessing capabilities, and their psychological significance is not as pronounced as it is for children. With increasing age, individuals may develop more mature cognitive and emotional regulation strategies to manage potential threatening information. Emotional regulation can reduce anxiety levels caused by stressful events, promoting good psychological adjustment (Aldao et al., 2010), and individuals who employ emotional regulation strategies tend to have a more positive and healthy psychological state, reducing the occurrence of test anxiety (Liu et al., 2021). This study did not replicate previous findings of anxiety-related group differences in the adult emotional Stroop task (Zhang et al., 2019), suggesting that there may be diverse developmental pathways in handling test anxiety among individuals. Some children may exhibit high sensitivity to test anxiety from an early age, while others may only show significant responses to such stimuli in adulthood. This diversity could be influenced by a combination of genetic factors, environmental conditions, and personal experiences.

This study did not find main effects for condition (threatening versus neutral) in both behavioral and N2 results. Traditional emotional Stroop tasks typically use emotional words (such as words related to anxiety or negative emotions) as threatening stimuli (Becker et al., 2001; Kappes and Bermeitinger, 2016), whereas this study employed test-related words as the threatening stimuli. This adaptation aimed to simulate cognitive disruptions specific to test anxiety. Although test-related words are closely associated with the anxiety experienced in test situations, they may not have elicited strong emotional responses or captured attention as emotional words do, leading to non-significant main effects for condition. These findings underscore the necessity of further exploring how different types of threat stimuli interact with the cognitive processes of individuals with test anxiety. Future studies could consider setting up three experimental conditions (stronger threatening stimuli such as high-arousal emotional words, test-related words, and neutral words) to better induce and compare the interference effects in emotional Stroop tasks.

The limitations of this study were primarily reflected in the failure to examine potential moderating variables between anxiety and cognitive control. According to the attentional control theory, anxiety can undermine central executive control, leading to improper allocation of cognitive resources and consequently, impaired task performance (Eysenck et al., 2007). We did not directly measure cognitive control or executive functions in this study, which may have limited our understanding of the effects across conditions and groups. This omission could have restricted our ability to fully interpret the non-significant main effects that were observed. Future research should incorporate assessments of cognitive control and executive functions as moderating variables to provide a more comprehensive understanding of how test anxiety impacts cognitive processing. Additionally, the reason for selecting 10–12-year-old children in this study, rather than younger children, is that they are just beginning to encounter more challenging academic exams. However, including 13–17-year-old adolescents (another group with a high incidence of test anxiety) remains very necessary. It would help to more comprehensively understand the relationships between age, test-related negative experiences, and attentional biases. Finally, we only used a cutoff score to form groups with high and low test anxiety in this study. Future research should treat test anxiety as a continuous variable to further explore how varying levels of test anxiety impact cognitive and emotional processes.

This study was the first to compare the attentional biases among children and adults with high and low test anxiety using the same experimental paradigm, revealing how test anxiety affected cognitive processing in both groups. Consistent with previous research, children exhibited poorer behavioral performance and larger ERP amplitudes, indicating that their cognitive and emotional regulation mechanisms are not yet fully mature. Even children with low test anxiety exhibited sensitivity to exam-related stimuli, which carried a strong subjective significance. Future research is expected to deepen the understanding of how test anxiety influences cognition from a developmental perspective and further translate basic research into practical interventions to alleviate test anxiety.

5. Conclusion

This study investigated the impact of test anxiety on cognitive processing in children and adults using the emotional Stroop task. The results demonstrated that children, compared to adults, exhibited reduced accuracy, longer response times, and increased ERP amplitudes when faced with test-related threatening stimuli, indicating that developmental stages significantly influenced cognitive responses to test anxiety. Notably, in children with low test anxiety, the N450 amplitude was significantly less negative in threatening conditions compared to neutral conditions, suggesting an increased sensitivity to threatening stimuli at lower levels of anxiety.

CRediT authorship contribution statement

Peibing Liu: Writing – review & editing, Writing – original draft, Visualization, Validation, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Shuliang Bai:** Writing – original draft, Formal analysis, Data curation. **Renlai Zhou:** Writing – review & editing, Project administration, Funding acquisition, Conceptualization.

Informed consent

Informed consent was obtained from all individual adult participants included in the study; assent was obtained from children.

Compliance with ethical standards

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional research committee at [anonymized for review] and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

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Declaration of competing interest

All authors have declared that no competing interests exist.

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Data availability

Data will be made available on request.

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