Journal of Experimental Child Psychology 263 (2026) 106421

Contents lists available at ScienceDirect

Journal of Experimental Child Psychology

journal homepage: www.elsevier.com/locate/jecp

Parental neural responses to threat impact children's test anxiety

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ARTICLE INFO

Keywords:
Test anxiety
Emotional Stroop
ERPs
Threat processing

ABSTRACT

Test anxiety impacts students' academic and psychological well-being, influenced not just by their own threat processing but also by their parents' threat processing. This study aims to explore the association between parents' threat processing and children's test anxiety. The study initially recruited 53 parent–child dyads, and 45 dyads (N = 90) remained after data screening, comprising 20 children with high test anxiety (Mean $_{age}$ = 10.44 years) and their parents (Mean $_{age}$ = 38.75 years), and 25 children with low test anxiety (Mean $_{age}$ = 11.13 years) and their parents (Mean $_{age}$ = 38.36 years). All participants completed the emotional Stroop task and had their event-related potentials recorded when processing test-related and non-test-related threatening words, using the interference effects of the N2 and N450 as indicators of threat processing. Results showed that only under non-test-related threatening conditions did parents' N2 and N450 interference effects negatively relate to children's test anxiety levels, s suggesting that parents' neural responses to general threat cues may play a role in shaping children's anxiety and informing family-based interventions.

Introduction

Test anxiety is a manifestation of evaluation anxiety, involving excessive worry and emotional arousal in exam or similar evaluative situations (Spielberger & Vagg, 1995). Globally, approximately 15 % – 22 % of students are affected by test anxiety (Huang & Zhou, 2019; Putwain et al., 2010; C. L. Thomas et al., 2017), and these rates may be particularly pronounced in highly competitive academic environments, such as many East Asian countries, where educational pressure is intense. Test anxiety not only negatively impacts academic performance but also increases the risk of depression and other psychological disorders (Gaudry & Spielberger, 1971; Leadbeater et al., 2012).

Cognitive processing biases, particularly threat processing biases, are considered core mechanisms contributing to the development and maintenance of test anxiety. Previous studies have indicated that individuals with high test anxiety (HTA), due to their tendency to focus on the negative consequences of tests, typically perceive test-related stimuli as threats, thus exhibiting an attentional bias towards test-related information (Alting & Markham, 1993; Putwain et al., 2011; Vasey et al., 1996; X. Zhang et al., 2018). Dong et al. (2015) explored the dynamics of this attentional bias using eye-tracking and found that HTA individuals initially engage early attention to test-related threatening pictures and eventually avoid them (Dong et al., 2016). Zhang et al. (2019) demonstrated using

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https://doi.org/10.1016/j.jecp.2025.106421
Received 29 November 2024; Received in revised form 13 November 2025;
Available online 24 November 2025
0022-0965/

event-related potentials (ERPs) that HTA individuals rapidly adjust their attention when faced with test-related threatening words, resulting in larger P1 and P2 amplitudes and smaller N2 amplitudes compared to neutral words. This rapid adjustment suggests that HTA individuals initially focus more on threat information and, if unable to suppress its interference, proceed to automatically process it. Such an attentional bias towards test-related stimuli is pivotal in the development of anxiety (Putwain et al., 2011; X. Zhang et al., 2018).

The emotional Stroop task has been widely used to evaluate individuals' cognitive processing of threatening information (Williams et al., 1996). In this task, participants are required to name the ink color of threatening or neutral words while ignoring word meanings. The facilitation of attention theory suggests that threatening stimuli can capture attention automatically, impairing color-naming performance (Williams et al., 1996), whereas the difficulty of disengagement theory proposes that attention may linger on threat-related information, delaying disengagement and response to task-relevant attributes (Fox et al., 2001). Both theories explain why threat-related stimuli interfere with performance, making the emotional Stroop task especially suitable for measuring threat processing in anxious individuals (Suárez-Pellicioni et al., 2015). Compared to adults, ERP studies focusing on children remain limited. Recent evidence has shown that children generally demonstrate reduced accuracy, slower response times, and different ERP patterns in emotional Stroop tasks compared to adults (Liu et al., 2025). Notably, Liu et al. found that among children with low test anxiety, N450 amplitudes were less negative under threatening conditions than neutral ones, suggesting developmental differences in conflict processing. However, studies simultaneously measuring ERP indicators in both children and their parents in the context of test anxiety remain scarce.

Extending previous findings, threat processing biases may not only reflect individual vulnerabilities but may also contribute to the intergenerational transmission of anxiety within families (Aktar et al., 2019; Waters et al., 2015). Previous studies have demonstrated that cognitive and behavioral patterns of anxiety are often transmitted from parents to children (Eley et al., 2015; Emerson et al., 2019). The Anxious Information Processing Biases Model (Creswell et al., 2010) and its integrated version (Aktar, 2022) suggest that similarities in information processing patterns between anxious parents and their children can lead to anxiety in children. For example, a mother's cognitive bias could predict a child's information search bias (Remmerswaal et al., 2016). Anxious parents tend to provide threat information by demonstrating anxious responses in ambiguous situations, which may play a significant role in the intergenerational transmission of anxiety (Emerson et al., 2019; Hadwin et al., 2006; Naar-King et al., 2016).

However, despite previous research attempting to explore the direct link between parents' attentional biases and children's test anxiety levels, the results have been mixed (Aktar et al., 2019; Mogg et al., 2012; Waters et al., 2015). Most prior studies have primarily relied on behavioral measures such as dot-probe tasks that only offer indirect estimates of attentional bias based on reaction times. These measures lack the temporal precision to capture distinct cognitive processing stages. In contrast, ERP technology, with its high temporal resolution, allows precise tracking of dynamic neural processes during threat exposure, enabling researchers to distinguish multiple stages of attention allocation, conflict detection, and cognitive control (Edwards et al., 2010; Luck et al., 2000; Mangun & Hillyard, 1995). ERPs can capture early attentional allocation (e.g., N2) and later conflict monitoring stages (e.g., N450), providing a more precise understanding of how anxious individuals process threat-related information at multiple processing stages (Liotti et al., 2000).Therefore, applying ERP measures to both parents and children provides an opportunity to examine whether patterns of threat processing show parallel intergenerational features, offering deeper insight into the cognitive-neural mechanisms underlying anxiety transmission within families.

This study employs the emotional Stroop task and ERPs to investigate the impact of parents' threat processing on their children's test anxiety. Previous research has shown that HTA individuals demonstrate automated features in early attention processing when confronted with threat (W. Zhang et al., 2019). Therefore, we predict that HTA children will exhibit smaller N2 and N450 interference effects in response to test-related threatening words during the emotional Stroop task. Furthermore, since previous research identified no significant attentional biases towards non-test-related threatening words in HTA individuals (X. Zhang et al., 2018), we predict that the ERP patterns of HTA children when dealing with non-test-related threatening words will resemble those of low test anxiety (LTA) children, characterized by larger N2 and N450 interference effects. We also hypothesize that the parents of HTA children will show similar information processing patterns, especially when facing test-related threatening words. To further explore the relationship between the threat processing of children and their parents, as well as their respective levels of test anxiety, we have incorporated the Actor-Partner Interdependence Model (APIM). The APIM is a method used for analyzing bidirectional relationships (Kenny & Cook, 1999), particularly suitable for examining mutual influences between individuals in family research (Bögels et al., 2008). Through the APIM, we analyzed the threat processing and test anxiety of parents and children while considering interactions between family members, including intra- and inter-personal effects. In summary, we hypothesize that parents' threat processing regarding test-related and non-test-related conditions is related to children's test anxiety levels.

Method

Participants

An a priori power analysis was conducted using the *pwrss* package in R (Bulus et al., 2023). Assuming a medium effect size (*partial* $\eta^2 = 0.06$), $\alpha = 0.05$, power = 0.80, 2 groups, and 2 repeated measurements (i.e., conditions), the required total sample size for detecting the group × condition interaction effect was estimated to be 33 participants. Thus, this study recruited 53 parent–child dyads through advertisements in a primary school in [city]. Based on Sarason's (1978) Test Anxiety Scale (TAS), children were divided into a high test anxiety group (HTA, $N = 32$) and a low test anxiety group (LTA, $N = 31$), with high anxiety scores ≥ 20 and low anxiety scores ≤ 12 (Newman, 1996). The inclusion criteria for child participants were: (1) aged between 9 and 12 years; (2) currently enrolled in primary school; and (3) having one primary caregiver (parent) willing to participate. The exclusion criteria were: (1) any diagnosis of neurological, psychiatric, or developmental disorders; (2) current use of psychotropic medications; and (3) uncorrected vision or hearing problems that could interfere with task performance. These exclusions were implemented to ensure that the observed differences in physiological and behavioral responses could be more confidently attributed to test anxiety itself, rather than to the potential confounding effects of comorbid conditions or medications. Additionally, participants who did not meet the criteria for either the high or low test anxiety group based on TAS scores were excluded from the final sample. Due to technical issues (6 dyads) and some participants not completing the experiment (3 dyads), the final sample included 20 HTA dyads and 25 LTA dyads. The average age in the LTA group was 10.44 years (SD = 0.77), and in the HTA group, it was 11.13 years (SD = 0.59), including 23 males and 22 females. The primary caregivers included 13 fathers and 32 mothers. The average age of parents in the HTA group was 38.75 years (SD = 1.45), with 70 % having a monthly income between 2000–5000 RMB (representing a lower-middle income bracket typical of families with primary school-aged children in the study area), and an average education duration of 14.60 years (SD = 1.96). The average age of parents in the LTA group was 38.36 years (SD = 1.11), with 64 % earning within the same income range, and an average education duration of 14.04 years (SD = 2.13). There were no significant differences between the groups in terms of age, income, and education level.

Procedure

This study was approved by the [Our institution] Research Ethics Committee. Participants were recruited from a larger survey project conducted prior to the laboratory session. In the initial survey phase, both children and their parents completed the Test Anxiety Scale (TAS) along with demographic questionnaires. Based on the TAS scores, participants were subsequently invited to the laboratory for EEG assessment. Since the TAS was administered during the initial survey phase prior to the laboratory session, participants did not complete the TAS immediately before the emotional Stroop task, minimizing potential priming effects of test anxiety on task performance.

Upon arrival at the laboratory, participants were briefed on the study procedures and signed informed consent forms. Parents and children were then brought to two separate EEG laboratories to complete the emotional Stroop task independently but concurrently, in order to avoid mutual influence. Then, children and parents completed the emotional Stroop task examining their neurophysiological responses to emotional stimuli for the electroencephalogram (EEG) session. The emotional Stroop task included both practice and experimental blocks, and the procedures were identical for both children and parents. During the task, participants were instructed to respond as quickly and accurately as possible to the visual stimuli presented on the screen.

After completing the EEG recordings, participants removed the EEG caps. All participants received a small gift as compensation for their participation.

Test anxiety scale

Test anxiety was measured using the Test Anxiety Scale (TAS; Sarason, 1977). The TAS consists of 37 items (0 = No, 1 = Yes), with a total score range of 0——37; higher scores indicate higher levels of test anxiety. This study used the Chinese version of TAS, which has satisfactory reliability and validity (Wang, 2001). Specifically, the retest reliability was 0.61, and the internal consistency coefficient was 0.64. In this study, the Cronbach's alpha of TAS was 0.89. The mean TAS scores for children were 7.50 (SD = 1.95) in the LTA group and 24.00 (SD = 3.17) in the HTA group. The corresponding mean TAS scores for parents were 11.02 (SD = 7.14) in the LTA group and 16.74 (SD = 8.16) in the HTA group.

Emotional Stroop task

The design of the emotional Stroop task is adapted from the task by S. J. Thomas et al., (2007). The task requires participants to name the color of the words displayed on the screen while ignoring their meaning. The colors of the words include four options: red, yellow, green, and blue. The meanings of the words fall under three conditions: (a) test-related threatening words (e.g., "finals," "failure"), (b) non-test-related threatening words (e.g., "harm," "liar"), and (c) neutral words (e.g., "handbag," "goose"). These words were selected from a test anxiety vocabulary database (Xin, 2013), chosen for their level of threat, relevance to tests, and matched by usage frequency, with 12 different words selected for each condition of test-related threat, non-test-related threat, and neutral. The task is divided into two experimental parts: (a) a practice section and (b) an experimental section. The practice section consists of three trials, all under neutral conditions (these words do not appear in the formal experiment). Participants receive feedback of "correct" or "incorrect" in the practice section, but no feedback is provided in the experimental section.

In the experimental section, each of the 36 words (12 words per condition) was presented in four different font colors (red, yellow, green, and blue), resulting in 144 unique word-color combinations. To minimize order effects and ensure balanced color representation, four pseudo-randomized sequences were generated. Each sequence contained one full presentation of all 144 word-color combinations in a pseudo-randomized order, and participants completed all four sequences, resulting in 576 trials in total. The task was divided into six blocks, with short breaks provided between blocks. The total task duration was approximately 30 to 40 min per participant. Each trial began with the presentation of a fixation cross ("+") for 1000 ms, followed by the target word, which appeared in the center of the screen for 300 ms against a black background. Participants were instructed to respond to the color of the word as quickly and accurately as possible by pressing one of four designated keys on a computer keyboard ('D' for red, 'F' for yellow, 'J' for green, 'K' for blue). Each trial terminated upon the participant's response or after 2000 ms if no response was made (as illustrated in

Fig. 1).

EEG recording and analysis

EEG data for both children and parents were recorded using a Compumedics Grael EEG amplifier and the Curry 8 system with 32-channel caps arranged in the standard 10–20 montage. Each child participant was fitted with a appropriately sized pediatric 32-channel EEG cap, while each parent was fitted with a standard adult 32-channel cap. The reference electrode was placed at the midpoint between FPz and Fz. EEG signals were sampled at 1024 Hz, and electrode impedance was kept below 10 kΩ throughout data collection. The EEG data were preprocessed using the MATLAB-based EEGLAB toolbox (Delorme & Makeig, 2004). Data were filtered with a 0.1 Hz high-pass filter and a 30 Hz low-pass filter, and re-referenced to the average of the bilateral mastoids (M1 and M2). Continuous EEG data were segmented into epochs ranging from − 200 ms to 1000 ms relative to stimulus onset. Baseline correction was applied using the pre-stimulus interval (−200 to 0 ms). Ocular artifacts were removed using independent component analysis (ICA; Jung et al., 2000). Only correct trials were included in the final ERP analyses.

EEG data quality was assessed separately for each child and parent at the single-trial level following preprocessing. Our exclusion criteria were based on two objective, quantitative thresholds. First, individual epochs (trials) with amplitudes exceeding ± 80 μV were automatically rejected as artifacts. The same preprocessing procedures were applied to both children and parents. The average number of valid trials included in the final ERP analysis after artifact rejection was: 541 trials for children in the HTA group, 548 trials for children in the LTA group, 557 trials for parents in the HTA group, and 568 trials for parents in the LTA group. Second, if any participant (child or parent) had more than 20 % of their total trials rejected according to this amplitude criterion, the entire parent–child dyad was excluded from all subsequent analyses. In total, 6 parent–child dyads were excluded after preprocessing.

For both children and parents, offline analysis of EEG data involved re-referencing to the average of the bilateral mastoids, filtering with a 30 Hz bandwidth, and correction for ocular artifacts. The analysis window for ERPs spanned from 200 ms before to 1000 ms after stimulus presentation, using the 200 ms pre-stimulus data as a baseline for baseline correction of the averaged ERP data. The time windows for the N2 and N450 components were determined separately for parents and children based on visual inspection of the grand average waveforms for each group, following standard procedures in ERP research (Luck, 2014). Considering developmental differences in ERP latencies, particularly for the N2 component, we selected time windows that align with prior literature indicating that the N2 typically occurs between 200–350 ms in adults and 250–500 ms in children (Folstein & Van Petten, 2008; Hoyniak, 2017; Lo, 2018). Specifically, the N2 component was defined as 200–240 ms for parents and 300–360 ms for children. For the N450 component, the time window was set at 390–480 ms for parents and 350–450 ms for children (Folstein & Van Petten, 2008; Hoyniak, 2017; Lo, 2018). The N2 and N450 amplitudes at the Fz electrode were calculated separately for each group. To ensure robustness, we additionally analyzed N2 and N450 amplitudes across a broader fronto-central ROI (F3, F4, FC3, FCz, FC4, C3, Cz, and C4), and the results converged with those at Fz (see Supplementary Materials).

Data analytic plan

We employed Mixed Linear Models (MLM) to investigate changes in behavioral and ERP interference effects among children and parents at different levels of test anxiety. MLM was conducted using the lme4 package (version 1.1–30; Bates et al., 2014) in R, which allows modeling both fixed and random effects, thus improving estimation accuracy under small sample conditions and accommodating intra-personal and inter-personal variability.

Two models were conducted separately for children and parents. We explored the effects of group (HTA group vs. LTA group), condition (non-test-related vs. test-related), and their interactions on behavioral interference effects (i.e., accuracy and reaction time) and ERP interference effects (i.e., N2 and N450). Here, test-related threat interference was calculated by the differences in ACC, RT, or ERP amplitudes between test-related threat conditions and neutral conditions, while non-test-related threat interference was determined by the differences in ACC, RT, or ERP amplitudes between non-test-related threat conditions and neutral conditions. To address

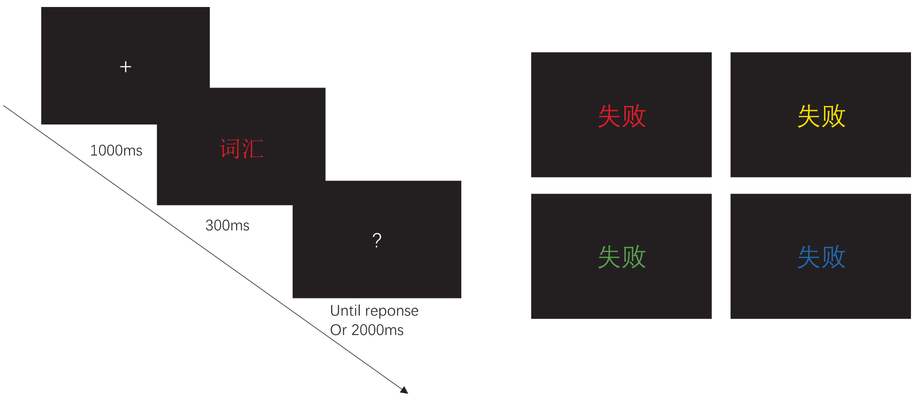

Fig. 1. Emotional Stroop Task.

data imbalance and small sample size, we used the Satterthwaite method for Type III ANOVA, which adjusts degrees of freedom and is particularly suitable for unequal group sizes and complex variance structures. To evaluate the mean effect differences between groups and conditions, we performed estimated marginal means (EMMs) analysis using the emmeans package (Lenth et al., 2019). Pairwise comparisons were conducted to assess significant differences between different condition combinations, and Bonferroni correction was applied for multiple comparisons. The model equation is as follows:

$$DV_{i,j}\ B_0 + B_1(condition) + B_2(group) + B_3(condition*group) + b_i + e_{i,j}$$

In the model, “condition” represents the experimental conditions, and “group” represents the test anxiety groups.

To explore the effects of N2 and N450 interference on test anxiety (TAS), this study used the Actor-Partner Interdependence Model (APIM) for data analysis, employing multilevel modeling to estimate actor effects and partner effects. The study included 45 dyads of children and parents, totaling 90 participants, with 45 children and 45 parents. To examine the potential influence of outliers on the model estimates, we computed Cook’s distance for each dyad in the APIM model. No values exceeded the standard cutoff of 4/n (0.089). The highest value was 0.072, suggesting that the findings are robust and not driven by extreme or influential cases.

In data processing, identifiers for children and parents were adjusted from ’1′ and ’2′ to ’-1′ and ’1′, respectively, to fit the needs of the multilevel model. In the multilevel model, the data of actors and partners are considered within a hierarchical structure, typically with the dyad as the unit of analysis. In the model, the interference effect for children serves as the actor variable for the children, reflecting how the child’s own interference effect impact their TAS; similarly, the interference effect for parents serves as the actor variable for the parents, used to assess how the parent’s N450 influences their own TAS. Additionally, these two variables are also used to estimate partner effects, i.e., how one individual’s interference effect impacts their partner’s TAS. We used an interactive tool designed for handling models through multilevel modeling (Kenny, 2015).

Results

ERP results

N2 interference effect

Fig. 2 shows the average ERP waveforms for children and parents at different levels of test anxiety under various stimulus conditions. The mean ERP interference effects for children and parents are shown in Fig. 3. For children’s N2 interference effects, the main

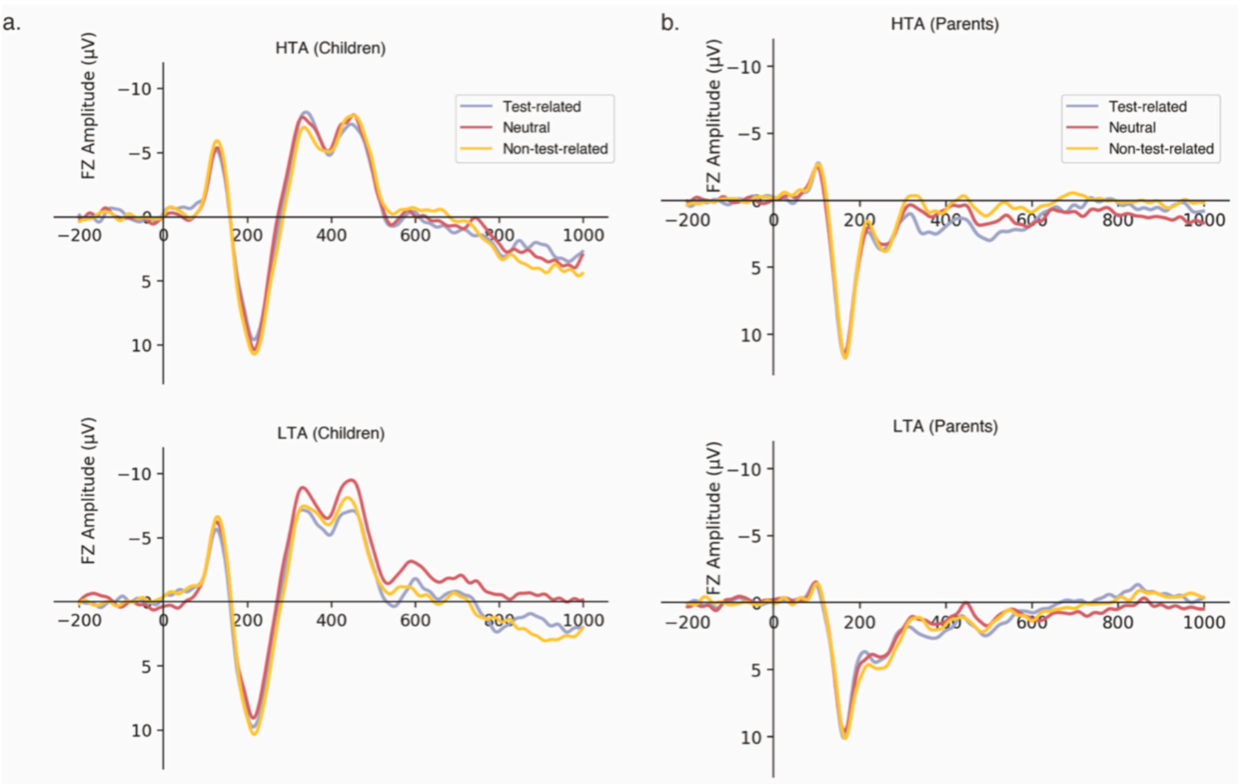

Fig. 2. Grand average ERPs elicited by test-related threatening, non-test-threatening and neutral words for the HTA and the LTA group of children and parents at Fz.

effect of group was not significant (F (1, 43) = 0.793, p = 0.378, $\eta_p 2$ = 0.018), nor was the main effect of experimental condition (F (1, 43) = 2.448, p = 0.125, *partial* η^2 = 0.054). However, the interaction between group and condition was significant (F (1, 43) = 6.084, p = 0.018, *partial* η^2 = 0.124). The marginal R^2 was 0.045, and the conditional R^2 was 0.706. Simple effects analysis showed that within the HTA group, N2 interference effect under non-test-related threat was significantly higher than that under test-related threat (t = 2.882, p = 0.006); in the LTA group, this difference was not significant (t = -0.48, p = 0.635).

For parents' N2 interference effects, the main effect of condition was not significant (F (1, 43) = 0.527, p = 0.472, *partial* η^2 = 0.012), nor was the main effect of group (F (1, 43) = 1.372, p = 0.248, *partial* η^2 = 0.031). The interaction between group and condition was significant (F (1, 43) = 5.822, p = 0.020, *partial* η^2 = 0.119). The marginal R^2 was 0.063, and the conditional R^2 was 0.444. Simple effects analysis showed that under non-test-related threat conditions, the interference effect in HTA was significantly smaller than in LTA (t = -2.297, p = 0.027); under test-related threat conditions, there was no significant difference in interference effect between HTA and LTA (t = 0.332, p = 0.742). In the HTA group, the difference in interference effects between non-test-related and test-related threat conditions was not significant (t = -1.314, p = 0.196). In the LTA group, the interference effect under non-test-related threat conditions was significantly smaller than under test-related threat conditions (t = 2.150, p = 0.037). Behavioral results and N2 and N450 topographies under different conditions are presented in the supplementary materials.

N450 interference effect

For children's N450 interference effects, the main effect of condition was not significant (F (1, 43) = 0.084, p = 0.773, *partial* η^2 = 0.002), but the main effect of group was significant (F (1, 43) = 4.362, p = 0.043, *partial* η^2 = 0.092). The interaction between group and condition was not significant (F (1, 43) = 0.402, p = 0.530, *partial* η^2 = 0.009). The marginal R^2 was 0.074, and the conditional R^2 was 0.560.

For parents' N450 interference effects, the main effect of group was not significant (F (1, 43) = 1.853, p = 0.181, *partial* η^2 = 0.041),

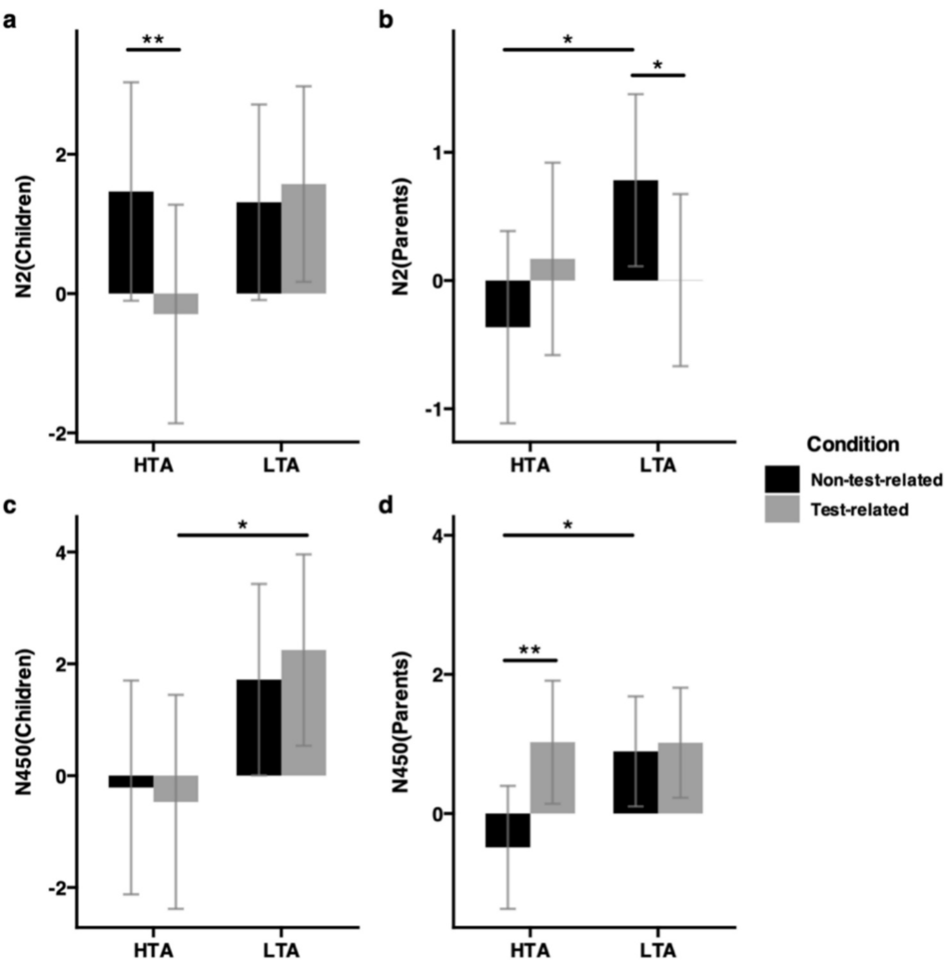

Fig. 3. Interference effects of N2 and N450 for HTA and LTA under different conditions, with error bars representing 95 % confidence intervals. Note. a. Children's N2 interference effects; b. Parents' N2 interference effects; c. Children's N450 interference effects; d. Parents' N450 interference effects. *p < .05, **p < .01, ***p < .001.

but the main effect of condition was significant (F (1, 43) = 6.002, p = 0.018, *partial* η^2 = 0.122). The interaction between group and condition was significant (F (1, 43) = 5.194, p = 0.028, *partial* η^2 = 0.108). The marginal R^2 was 0.093, and the conditional R^2 was 0.515. Simple effects analysis showed that under non-test-related threat conditions, the interference effect in HTA was significantly smaller than in LTA (t = -2.343, p = 0.024); in the HTA group, the interference effect under non-test-related threat conditions was significantly smaller than under test-related threat (t = -3.332, p = 0.002).

Correlation analyses and intra- and inter- personal effects

As shown in Table 1, correlation analyses of children and their parents' TAS scores, N2 and N450 interference effects revealed that under non-test-related conditions, children's test anxiety levels were significantly negatively correlated with their own N450 interference effects (r = -0.33, p = 0.028), and also significantly positively correlated with parents' test anxiety levels (r = 0.31, p = 0.013), their parents' N2 (r = -0.37, p = 0.050) and N450 interference effects (r = -0.31, p = 0.036). However, under test-related conditions, they were only significantly negatively correlated with their own N2 (r = -0.38, p = 0.010) and N450 (r = -0.42, p = 0.004) interference effects.

Intra-personal and inter-personal effects under test-related conditions

As shown in Table 2, for N2 interference effects, in terms of actor effects, children's N2 interference effects significantly impact TAS (β = -1.037, SE = 0.387, p = 0.009). However, parents' N2 interference effects on TAS are not significant (β = 0.947, SE = 0.162, p = 0.295). Regarding partner effects, the effect from parents to children is not significant (β = -0.161, SE = 0.064, p = 0.677), and the effect from children to parents is also not significant (β = 0.367, SE = 0.059, p = 0.686). The standardized coefficients and significance of each path are shown in Fig. 4.

For N450 interference effects, in terms of actor effects, children's N450 interference effects have a significant negative impact on TAS (β = -0.86, SE = 0.44, p = 0.002). Parents' N450 interference effects on TAS are not significant (β = 1.05, SE = 0.22, p = 0.155). In terms of partner effects, the impact from parents to children is not significant (β = 0.61, SE = 0.12, p = 0.408), and the impact from children to parents is also not significant (β = -0.37, SE = 0.20, p = 0.181).

Intra-personal and inter-personal effects under non-test-related conditions

For the N2 interference effects, in terms of actor effects, the impact of children's N2 interference effects on TAS are not significant (β = -0.140, SE = 0.057, p = 0.698). The impact of parents' N450 interference effects on TAS are also not significant (β = -0.127, SE = 0.029, p = 0.853). In terms of partner effects, the impact from parents to children is significant (β = -1.673, SE = 0.357, p = 0.016), while the impact from children to parents is not significant (β = 0.124, SE = 0.054, p = 0.731).

For the N450 interference effects, in terms of actor effects, children's N450 interference effects have a significant negative impact on TAS (β = -0.681, SE = 0.311, p = 0.028). The impact of parents' N450 interference effects on TAS are not significant (β = -0.491, SE = 0.132, p = 0.392). In terms of partner effects, there is a significant negative impact from parents to children (β = -1.179, SE = 0.294, p = 0.037). The impact from children to parents is not significant (β = -0.37, SE = 0.20, p = 0.181). The standardized coefficients and significance of each path are shown in Fig. 4.

Discussion

This study aims to explore how parents' threat processing is associated with their children's test anxiety, with a particular focus on the neural response patterns of children and their parents under test-related and non-test-related threatening conditions, and the relationship between these patterns and test anxiety. The results indicate that when facing non-test-related threatening words, there are significant differences in the threat processing between HTA and LTA individuals. In the context of test-related threatening words, only the children's neural responses were significantly associated with their own test anxiety levels; however, under non-test-related threatening words, the parents' neural response patterns were significantly correlated with the children's anxiety levels, suggesting an association between parents' processing of non-test-related threatening words and their children's test anxiety.

ERP results indicate that there are no significant differences in the N2 interference effects between HTA and LTA children, regardless of whether the threatening words are test-related or unrelated. However, within-group comparisons reveal that the N2 interference effect under test-related conditions is significantly lower than under non-test-related conditions for HTA children, while LTA children show no difference between these conditions. This suggests that HTA children may use more effective automatic

Table 1a

Correlations between Children's and Parents' Test Anxiety, N2 Interference Effects, and N450 Interference Effects under Non-Test-Related Condition.

	TAS (Child)	TAS (Parent)	N2 (Child)	N450 (Child)	N2 (Parent)	N450 (Parent)
TAS (Child)	–	**.31***	–.11	**–.33***	**–.37***	**–.31***
TAS (Parent)		–	0.05	–.04	–.02	–.13
N2 (Child)			–	**.62****	0.16	–.03
N450 (Child)				–	0.29	0.06
N2 (Parent)					–	**.56****
N450 (Parent)						–

Note. *p < .05, **p < .01, ***p < .001.

Table 1b
Correlations between Children's and Parents' Test Anxiety, N2 Interference Effects, and N450 Interference Effects under Test-Related Condition.

	TAS (Child)	TAS (Parent)	N2 (Child)	N450 (Child)	N2 (Parent)	N450 (Parent)
TAS (Child)	–	**.31***	**–.38***	**–.42****	0	0.06
TAS (Parent)		–	–.04	–.17	0.15	0.19
N2 (Child)			–	**.64****	0.15	0.11
N450 (Child)				–	0.09	0.14
N2 (Parent)					–	**.44****
N450 (Parent)						–

Note. *$p < .05$, **$p < .01$, ***$p < .001$.

Table 2
Effect Estimates for child and parent under test-related and non-test-related condition.

Effect	Test-related threat Estimate	SE	95 % CI	Non-test-related threat Estimate	SE	95 % CI
Intrapersonal effect						
Child N2 → Child TAS	−1.04 *	0.39	[-1.795, −0.280]	−0.14	0.06	[-0.844, 0.564]
Parent N2 → Parent TAS	0.95	0.16	[-0.814, 2.708]	0.12	0.05	[-0.581, 0.829]
Child N450 → Child TAS	−0.86 **	0.44	[-1.393, −0.318]	−0.68 *	0.31	[-1.277, −0.085]
Parent N450 → Parent TAS	1.05	0.22	[-0.383, 2.483]	−0.49	0.13	[-1.612, 0.629]
Interpersonal effect						
Parent N2 → Child TAS	0.37	0.06	[-1.404, 2.138]	−1.67 *	0.36	[-3.009, −0.337]
Child N2 → Parent TAS	−0.16	0.06	[-0.914, 0.593]	−0.12	0.03	[-1.465, 1.211]
Parent N450 → Child TAS	0.61	0.12	[-0.829, 2.049]	−1.18 *	0.29	[-2.269, −0.089]
Child N450 → Parent TAS	−0.37	0.2	[-0.904, 0.167]	−0.07	0.04	[-0.685, 0.541]

Note. *$p < .05$, **$p < .01$, ***$p < .001$.

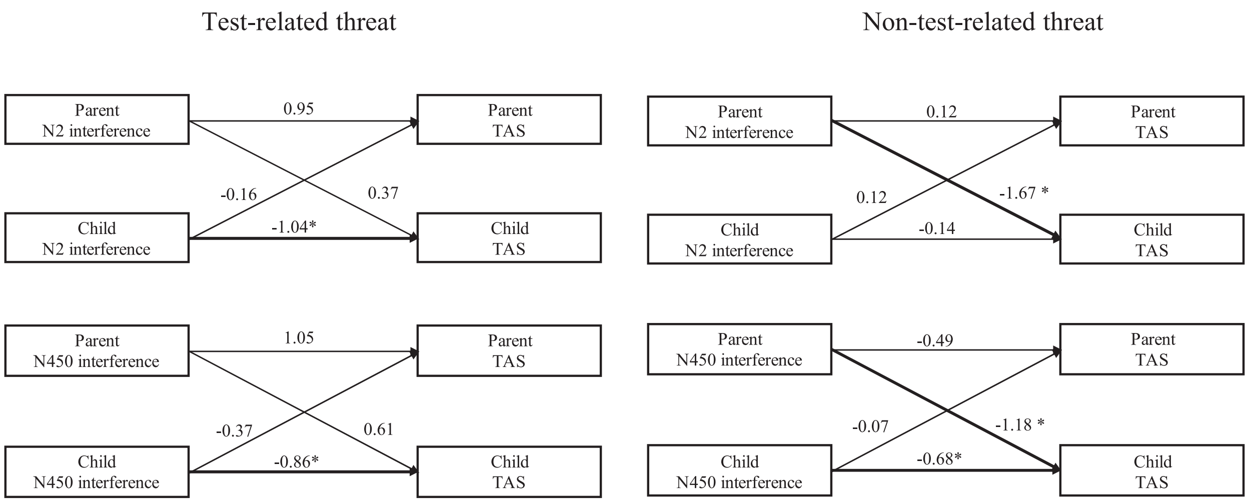

Fig. 4. The APIM model of the intra- and inter-personal impacts of N2 and N450 interference on parents' and children's TAS. Note. *$p < .05$, **$p < .01$, ***$p < .001$.

processing mechanisms to reduce the interference of threat information. This aligns with the interpretation proposed by Zhang et al. (2019), who examined adult participants, suggesting that smaller N2 interference effects may reflect more effective automatic processing of threatening information. Extending this interpretation to children, our findings suggest that similar mechanisms of automatic threat processing may also operate in highly test-anxious children when facing test-related threatening words. Such automatic processing may include rapid identification and inhibition of threatening words, thus reducing their impact on task performance. This mechanism can be seen as an adaptive strategy, enabling HTA children to maintain task performance under test-related stress. For the N450 component, we find that under test-related conditions, the N450 interference effect is significantly smaller for HTA children than for LTA children. This indicates that HTA children may have automatically processed test-related threatening words, thereby reducing the depth of cognitive processing of such information. According to research conducted with adult participants, words with stronger subjective significance in the emotional Stroop task elicit smaller N450 amplitudes (Imbir et al., 2017), supporting the notion that HTA children tend to minimize processing depth when facing test-related threat words. In contrast, test-related threatening words may have less subjective significance for LTA children, thus eliciting greater N450 interference effects.

ERP results indicate that in non-test-related conditions, HTA parents exhibit significantly smaller N2 interference effects than LTA parents, supporting our hypothesis that HTA parents may use automated cognitive processing mechanisms to cope with threats, thus conserving attentional resources. Additionally, HTA parents show smaller N450 interference effects than LTA parents, suggesting less deep semantic processing for non-test-related threatening words. These findings imply that HTA parents possess a broader anxiety cognitive pattern that extends beyond test-related stress, influencing their information processing across various situations. This automated processing might be an adaptive strategy for dealing with daily threats. Furthermore, for LTA parents, the N2 interference effect is significantly smaller for test-related than non-test-related threatening words, indicating that HTA parents process both types of threatening words similarly, likely through automated mechanisms. In the HTA group, N450 interference from test-related threatening words is greater than from non-test-related threatening words, suggesting deeper processing due to greater sensitivity or perceived impact on their children. In contrast, LTA parents show no significant difference in N450 effects between threat types, indicating that LTA parents adopt a similar processing strategy for both types of threatening words.

APIM results indicate that under test-related conditions, the N2 and N450 interference effects of children can only predict their own test anxiety. This may be because the stress associated with test-related threatening words is more individualized among children, with each person responding independently based on their experiences and emotional regulation strategies. Compared to non-test-related threatening words, test-related threatening words are more personalized and directly trigger individual concerns about exam performance. Parents are less likely to encounter test-related scenarios in everyday life, and their anxiety responses in these situations may not directly transfer to their children. Notably, under non-test-related threat conditions, the N2 and N450 interference effects of parents can predict their children's test anxiety, while children's interference effects do not predict their parents' test anxiety. These results suggest that parents' cognitive reactivity to threat-related information may shape their children's anxiety-related processing patterns. Under non-test-related threat conditions, family members are more likely to assess and respond to threats collectively, making it easier for children to perceive and emulate their parents' anxious information. In this context, family interactions and influences are likely more pronounced, especially in shaping children's psychological health and anxiety management strategies. Although non-test-related threatening words are not directly linked to individual exam situations, parents' responses may serve as a model for children, especially in how to assess and process general threats. This finding supports the hypothesis of the Anxious Information Processing Biases Model (Aktar, 2022). The theory suggests that anxious cognition is transmitted between parents and children, with parents' threat processing patterns potentially being learned and internalized by children, forming their own information processing biases. Parents' anxiety or handling strategies when facing general threats may directly influence children, particularly as they observe and learn how to assess and respond to threats in their environment. This information is conveyed through spontaneous dialogues, both consciously and unconsciously, transferring evaluative cognition to children (Fivush, 1991; Murray et al., 2014; Pass et al., 2012). These results also demonstrate significant differences in the ways family members interact and influence each other in different types of threat scenarios. Specifically, test-related threatening words may more frequently trigger individual-related anxiety processing mechanisms, while non-test-related threatening words emphasize family dynamics and the impact of parents on children's anxiety. Children's N2 and N450 interference effects were unable to predict parents' test anxiety, likely because in family relationships, parents' behaviors and emotional states usually have a greater impact on children than children on parents.

Despite the valuable insights provided by this study, several limitations of the present study should be acknowledged. First, its cross-sectional design limits our ability to infer causal relationships between neural responses and test anxiety levels. Future research should adopt a longitudinal design to track the dynamic changes between test anxiety and family members' threat processing. Second, the relatively small sample size for the APIM analyses (45 parent–child dyads) may limit statistical power. While larger samples are typically recommended for stable estimation in APIM models, the EEG recordings from both parents and children in this study provide a unique dyadic perspective. Despite the sample size limitation, these preliminary findings offer valuable insights and highlight the need for future research with larger samples. Also, the generalizability of our findings is limited to typically developing children without comorbid neurological or psychiatric diagnoses. Moreover, although we excluded children with clinical levels of non-test-related anxiety, it is still possible that the observed APIM effects reflect broader anxiety-related processes rather than mechanisms specific to test anxiety. Future studies should aim to include more clinically heterogeneous samples to further clarify this issue. Last, considering the differences in ERP component time windows, such as the variability in the timing of the N2 component between children and adults (children between 250 to 500 ms, adults within 200 to 350 ms; Folstein & Van Petten, 2008; Hoyniak, 2017; Lo, 2018), it may be challenging to ensure that the same ERP components are captured across all age groups. Future studies could integrate time–frequency analysis methods, which represent EEG data as oscillations, providing an intuitive expression of neurophysiological mechanisms that does not rely on identifying specific ERP components (Morales & Bowers, 2022).

Conclusion

This study finds that the threat processing patterns of non-test-related threatening words parents use significantly impact their children's test anxiety, while in test-related threat conditions, children's neural responses only independently predict their own anxiety levels. These results support the Anxious Information Processing Biases Model, emphasizing the emotional and cognitive interplay between parents and children, especially when facing more general threat cues. These findings not only help to understand the intergenerational transmission of anxiety but also provide a theoretical basis for future interventions and support for anxious children and their families.

CRediT authorship contribution statement

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

Funding

This work was supported by grants from the National Natural Science Foundation of China (32471094).

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.

Acknowledgement

We would like to thank all the teachers, children, and parents who participated in this study. Their invaluable contributions and cooperation made this research possible.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jecp.2025.106421.

Data availability

Data will be made available on request.

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