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Effect of test anxiety on visual working memory capacity using evidence from event-related potentials

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Abstract

This study examined the effects of test anxiety on working memory capacity. Studies have demonstrated that individuals with trait social anxiety disorder exhibit increased visual working memory capacity and that those with trait anxiety exhibit decreased working memory capacity. Test anxiety may also induce unique effects on individuals' working memory capacity, and we thus employed the change detection task to explore such effects. Participants were divided into high- and low-test anxiety groups. We used K score and contralateral delay activity (CDA) amplitude to measure working memory capacity, focusing on processing effectiveness and efficiency. The study results revealed that deficits in the working memory capacity of individuals in the high test anxiety group manifested in the CDA amplitude rather than in the K score. The CDA amplitude of the high test anxiety group did not increase after load 3, and that of the low test anxiety group did not increase after load 4. No difference was observed in the K scores of the two groups. The study concluded that test anxiety impairs processing efficiency but not processing effectiveness.

KEYWORDS

CDA amplitude, ERPs, K score, test anxiety, working memory capacity

1 | INTRODUCTION

Test anxiety is a physiological condition associated with apprehension of failure or negative outcomes from exams or similar situations (Zeidner, 1998). Text anxiety occurs when individuals consider test results to be paramount, with multiple studies having reporting that approximately 20% of students experience test anxiety (Huang & Zhou, 2019; Putwain & Daly, 2014). Most evidence indicates that test-anxious individuals exhibit deficiency in their inhibitory control ability (Wei et al., 2020, 2021; Zhang et al., 2019) and attention (Dong et al., 2017; Zhang et al., 2015). However, other core components of executive functioning (Diamond, 2013) of test-anxious individuals are seldom investigated.

Studies have suggested that the widespread allocation of attentional resources by anxious individuals is conducive to discovering potential threat information (Moriya & Sugiura, 2012). Bishop (2009) used perceptual processing tasks in combination with interfering stimuli, determining that individuals with trait anxiety processed both the target and interfering stimuli. Perceptual load theory states that individuals with more attentional resources process interfering stimuli in task contexts (Lavie, 2005; Moriya & Sugiura, 2012). Accordingly, scholars have indicated that trait socially anxious individuals have a high working memory capacity (Moriya & Sugiura, 2012). The aforementioned findings were further supported through an attentional network task and change detection task (CDT), which identified that alertness, the orientation of the neutral stimuli, and working memory capacity all positively predicted the level of social anxiety (Moriya, 2018).

The effect of the various anxiety subtypes on working memory has been shown to be inconsistent across different studies. Trait anxiety restricted visual working memory capacity for basic color squares (Qi, Chen, et al., 2014) and faces (Yao et al., 2018), with a similar negative influence identified in more broadly defined anxiety (Moran, 2016) and generalized anxiety (Yoon et al., 2018). Researchers have reported a high visual working memory capacity in trait social anxiety (Moriya, 2018; Moriya & Sugiura, 2012), although the closely related math anxiety (Ashcraft & Kirk, 2001; Ashcraft & Krause, 2007) and state anxiety (Stout & Rokke, 2010; Ward et al., 2020) are found to reduce working memory capacity. Due to these inconsistencies, we further explore high test anxiety (HTA) individuals' working memory capacity characteristics.

Worry in individuals with text anxiety and their inhibitory control signal deficiency and reduced working memory capacity provides us with two additional sources of evidence (Eysenck & Derakshan, 2011; Zhang et al., 2019). Individuals with test anxiety worry about their performance during a task (Angelidis et al., 2019; Van Ameringen et al., 2003). Hayes et al. (2008) conducted an experiment in which they induced worry in participants by asking them to think about the recent worrisome and positive events in their daily lives. The results revealed that a high level of worry indicated reduced working memory capacity and that diverting attention away from worrisome events was difficult. Worry and working memory capacity affect each other dynamically (Trezise & Reeve, 2016). Worry affects working memory capacity, and impaired working memory then generates worry, thereby increasing initial deficiencies over time. Noritake et al. (2018), in a study on stressful scenarios, observed that worry negatively affected visuospatial working memory capacity.

Working memory and inhibitory control ability, both core components of executive function, are positively correlated (Kane et al., 2007). Zhang et al. (2019) reported that individuals with test anxiety exhibited inhibitory control deficiency in terms of emotion (emotional Stroop) and cognition (numerical Stroop). Insufficient inhibitory control ability signals reduced working memory capacity (Qi, Chen, et al., 2014). In the study by Zhang et al. (2019), HTA individuals failed to suppress the interference of test-related threat stimuli, leading to the fine processing of the stimuli (P3 component) and the subsequent stimulation of corresponding negative emotions (late positive potential component). Studies have revealed that individuals with high working memory capacity can effectively filter negative interference stimuli from their working memory, but those with low working memory capacity cannot (Ye et al., 2018). Therefore, we speculated that individuals with HTA have reduced working memory capacity.

Different experimental stimuli and paradigms are employed for different anxiety subtypes. The CDT is a widely used paradigm in the field of working memory (Qi, Chen, et al., 2014; Qi, Ding, et al., 2014; Stout et al., 2013; Vogel & Machizawa, 2004; Vogel et al., 2005) and is advantageous for its accurate operational definition of working memory ability. The implementation of the working memory electroencephalography (EEG) indicator was another milestone contribution to the field (Shen et al., 2012). The CDT uses the contralateral control method to eliminate factors unrelated to memory load and then calculates the K score and contralateral delay activity (CDA) amplitude. The K score and CDA amplitude increase with the number of objects encoded in working memory during the maintenance stage. After individuals reach their working memory capacity, no further increase is observed. Therefore, the K score and CDA amplitude are widely employed to assess working memory capacity (Luria et al., 2016; Vogel & Machizawa, 2004; Vogel et al., 2005).

In the CDT, the K score reflects the number of items stored in working memory, and CDA amplitude is the EEG index reaching an asymptote near the working memory capacity limit (Luck & Vogel, 2013). Corresponding to the attentional control theory of anxiety (Eysenck & Derakshan, 2011; Eysenck et al., 2007) and similarly group designed research on trait anxiety (Qi, Chen, et al., 2014; Qi, Ding, et al., 2014), the K score reflects an individual's ability to complete a cognitive task or their processing effectiveness. The CDA amplitude reflects processing efficiency, which is the relationship between the results of a cognitive task and the resources consumed in its completion. Attentional control theory states that anxiety impairs processing efficiency but not effectiveness (Eysenck & Derakshan, 2011; Eysenck et al., 2007). Therefore, we hypothesized that the deficit in the working memory of individuals with HTA manifests more in their CDA amplitude than in their K scores. Anxiety-related research has also indicated that anxiety affects neural processing (Berggren & Eimer, 2021; Eysenck & Derakshan, 2011; Eysenck et al., 2007; Qi, Chen, et al., 2014). This study used a combination of behavioral and electrophysiological indicators to distinguish test anxiety from other subtypes within the domain of working memory capacity.

This study explored whether individuals with test anxiety exhibit deficient working memory capacity. The Test Anxiety Scale (TAS) was adopted for the HTA and low test anxiety (LTA) groups, and the CDT with colored squares was used to measure working memory capacity.

2 | METHOD

2.1 | Measurement instruments

We adopted Sarason's TAS (Sarason, 1978). The scale comprises 37 questions with two options for each:

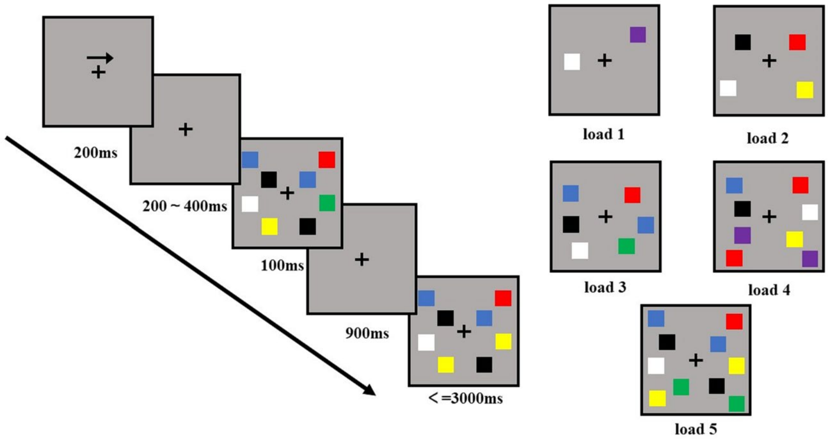

FIGURE 1 Working memory task. Signal trial flow. (a) In this trial, the participants were required to remember four colored squares on the right side of an array in the encoding stage and keep the information in mind during the maintenance stage. Because the third colored square (from top to bottom) changed, the participants were required to press the corresponding button. (b) Participants were required to remember five load conditions in the experiment in turn with one to five colors

"yes" having a value of 1, and 0 indicating "no." TAS score ≥20 is HTA, and ≤12 is LTA (Sarason, 1978; Wei et al., 2020; Zhang et al., 2019). TAS widely is used in experimental environments (Wei et al., 2020, 2021; Zhang et al., 2019). The test–retest reliability coefficient of the TAS was 0.61, and the homogeneity coefficient was 0.64 (Wang, 2001). We also employed the Test Anxiety Inventory (TAI). Cronbach's alpha of TAS was 0.89 and that of TAI was 0.93.

2.2 | Participants

Advertisements were posted on Nanjing University's online recruitment forum. A total of 718 questionnaires were received, and participants who met the criteria for depression on the Beck Depression Inventory were excluded. In total, we selected 24 participants to comprise the HTA group (6 men, 18 women, average age of 20.38 years) and 22 participants for the LTA group (7 men, 15 women, average age of 20.95 years) according to the TAS score. The TAS scores of the two groups were significantly different (HTA: 25.62 ± 3.62, LTA: 8.68 ± 3.03; $t(44) = 17.13$, $p < .001$). The difference was also supported by TAI (HTA: 47.33 ± 8.20, LTA: 26.00 ± 2.16; $t(44) = 11.82$, $p < .001$). However, age did not significantly differ between groups $t(44) = 1.00$, $p = .32$. All participants were right-handed and signed an informed consent form before the experiment. In terms of the experiment timing, the examination week was avoided, and no major examination was held in the two weeks before and after the experiment.

Gpower software was used to calculate the total number of participants in the experiment (Faul et al., 2007, 2009). We selected a repeated measures analysis of variance (ANOVA; within–between interaction) as the statistical test. The selected effect size was 0.25. Two groups were selected. The number of measurements selected was 5, and default values were chosen for the remaining parameters to estimate the number of participants required in the experiment. The total sample size required in the experiment was 32. In addition, we referred to the number of participants in a previous similar experimental design (Qi, Chen, et al., 2014; Ye et al., 2018).

2.3 | Working memory task

This study used the CDT with colored squares (Qi, Chen, et al., 2014; Vogel et al., 2005) to test the working memory capacity of individuals with HTA.

The RGB values of the colored squares in the task (Figure 1) were as follows: black (0, 0, 0), white (255, 255, 255), red (255, 0, 0), green (0, 255, 0), blue (0, 0, 255), yellow (255,255,0), and purple (160,32,240). Participants sat approximately 80 cm away from a 17-inch computer screen. The left and right side memory cues were presented in a rectangular box with a view angle of $4° \times 7.6°$. The angle from the left and right stimuli to the central fixation point was 2.85°. The distance between the presented stimuli was at least 2°. The size of each colored square was $0.68° \times 0.68°$.

In each trial, memory cues on the right and left sides were presented for 200 ms at a ratio of 1:1. Subsequently, a 200–400 ms random window was presented to eliminate the participant's expectation of the upcoming stimulus. Thereafter, the memory cues were displayed for 100 ms before disappearing. The stimulus was presented on both sides of the screen, but the participant was required to remember only the colored square on the side targeted by the memory cue before. The participants were required to retain the memory items in their working memory for 900 ms. Finally, probes were presented for 3000 ms. Participants were asked to respond to whether they saw a change between the memory and the probes. The ratio of change and no change was 1:1. The interval between trials was 2000 ms. In total, the experiment comprised 12 blocks of 80 trials each, 192 trials each load. The entire experiment required approximately 1.5 h. The interval between trials was 2000 ms to allow the participants' electrical activity in the brain to return to baseline after each trial. Participants had 15–20 practice trials before starting the formal experiment to understand the task requirements.

CDA is the event-related potential (ERP) component induced by the differential activation of the left and right hemispheres. The participants were strictly required to stare at the central fixation point during the task to prevent deviations caused by horizontal eye movements. Participants were instructed to avoid blinking as much as possible to ensure that as many valid trials as possible would be retained in the subsequent analysis.

2.4 | Electroencephalography

Neuroscan 64-channel Ag-AgCl electrodes EEG equipment was used, and we positioned the electrodes in accordance with the international 10–20 system. For data collection, the left mastoid (M1) was used as the reference, and data from the right mastoid (M2) were recorded simultaneously. The ground point was the midpoint between Fpz and Fz. Electrodes were placed above and below the left eye to record vertical electrooculography (EOG) data, and electrodes were placed on the left and right outer canthi to record horizontal EOG data. The filter bandpass for collecting EEG data was 0.01–100 Hz, the sampling frequency of each lead was 1000 Hz, and the resistance between each electrode and the scalp was ≤10 kΩ. During offline analysis, the sampling frequency was reduced to 500 Hz, a 0.1–30-Hz bandpass was used for filtering, and the offline filter is 24 db/octave slope. The average value of M1 and M2 was used as a reference. We excluded trials with excessive horizontal EOG and blinking in the maintenance stage as well as trials with head movement. In ERP, only the trials during which participants responded correctly are retained for data analysis.

The proportion of trials retained was 84.23% in the HTA group and 86.25% in the LTA group. There was no significant difference in the number of trials between the HTA group (M = 808.63, SD = 77.88) and LTA group (M = 828.00, SD = 64.38, $t(44)$ = 0.92, p = .37), and there was no difference when examing each condition (ps > .25). The number of reserved trials under each condition in the LTA group is (load 1:176.64 ± 14.27, load 2:177.09 ± 13.01, load 3:170.00 ± 13.78, load 4:157.14 ± 15.29, load 5:147.14 ± 13.29) and in the HTA group (load 1:175.71 ± 12.64, load 2:171.71 ± 17.84, load 3:165.79 ± 16.69, load 4:153.87 ± 18.51, load 5:141.54 ± 19.79).

2.5 | K scores and CDA amplitude analysis

For calculating K score, we mainly used Pashler's $K = N \times (HR - FA)/(1 - FA)$, which is mainly used for the whole-display recognition paradigm (Rouder et al., 2011). In this formula, K denotes working memory capacity and N denotes the number of items that must be memorized. HR denotes the hit rate, or the probability of correctly identifying a change. FA denotes the false alarm rate, or the probability of incorrectly responding to no change. We also calculated Cowan's $K = N \times (HR - FA)$, which is mainly used for the single-probe recognition paradigm, to verify the consistency of the two K scores on the trend between the HTA and LTA groups. We also calculated accuracy and reaction time for each condition.

For the analysis of ERPs, we used data from 200 ms before the stimulus onset as the baseline. We mainly analyzed the stimulus presentation and subsequent data within 1200 ms. The total selected analysis time was 1400 ms, and the experimental trials were averaged according to the conditions. The CDA time window for statistic analysis was 400–900 ms after the onset of the memory stimulus. CDA amplitude denotes the difference between the contralateral and ipsilateral waves (Vogel & Machizawa, 2004; Vogel et al., 2005). The ipsilateral region in this study was the left posterior brain area when the memory item was on the left and the right posterior brain area when the memory item was on the right. The contralateral region was the right posterior brain area when the memory item was on the left and the left posterior brain area when the memory item was on the right (Figure 2). We selected five parietal and parieto-occipital electrode pairs (P3 and P4, P5 and P6, P7 and P8, PO3 and PO4, and PO7 and PO8) to calculate CDA. The five pairs of electrodes are widely used in clinical research (Qi, Chen, et al., 2014; Qi, Ding, et al., 2014) and for studying working memory neural mechanism (Stormer et al., 2013; Xie & Zhang, 2018). We performed Greenhouse–Geisser correction of p values for statistical analysis and employed the Bonferroni correction for comparison between conditions. EEG data analysis was performed in EEGLAB based on MATLAB (Delorme & Makeig, 2004).

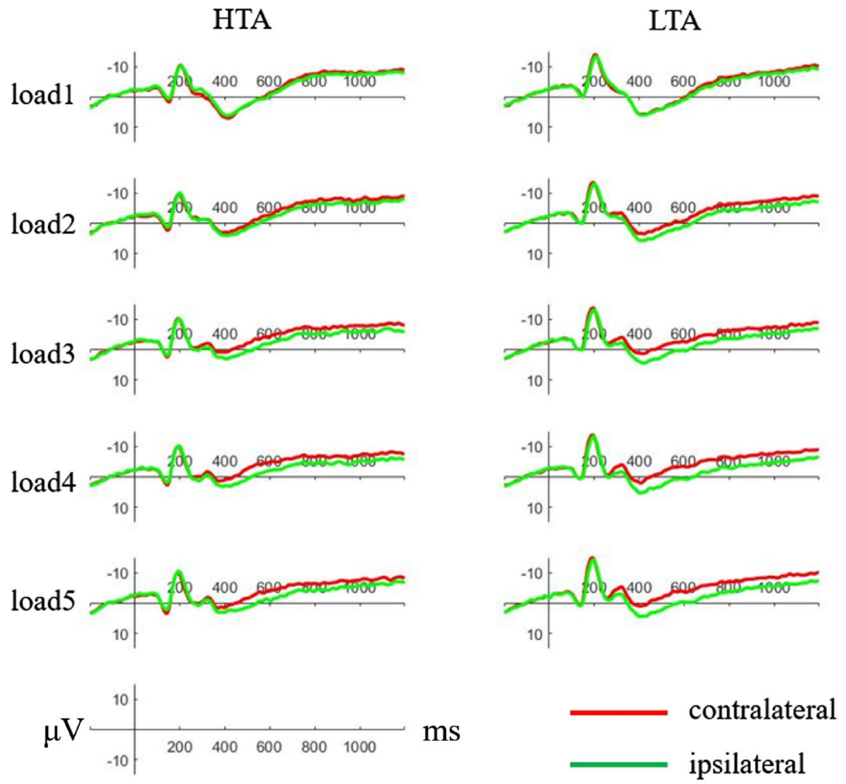

FIGURE 2 Ipsilateral/contralateral results. The red line denotes the contralateral ERP, and the green line denotes the ipsilateral ERP. The CDA component is the difference between the two ERPs. CDA, contralateral delay activity; ERP, event-related potential; HTA, high test anxiety; LTA, low test anxiety

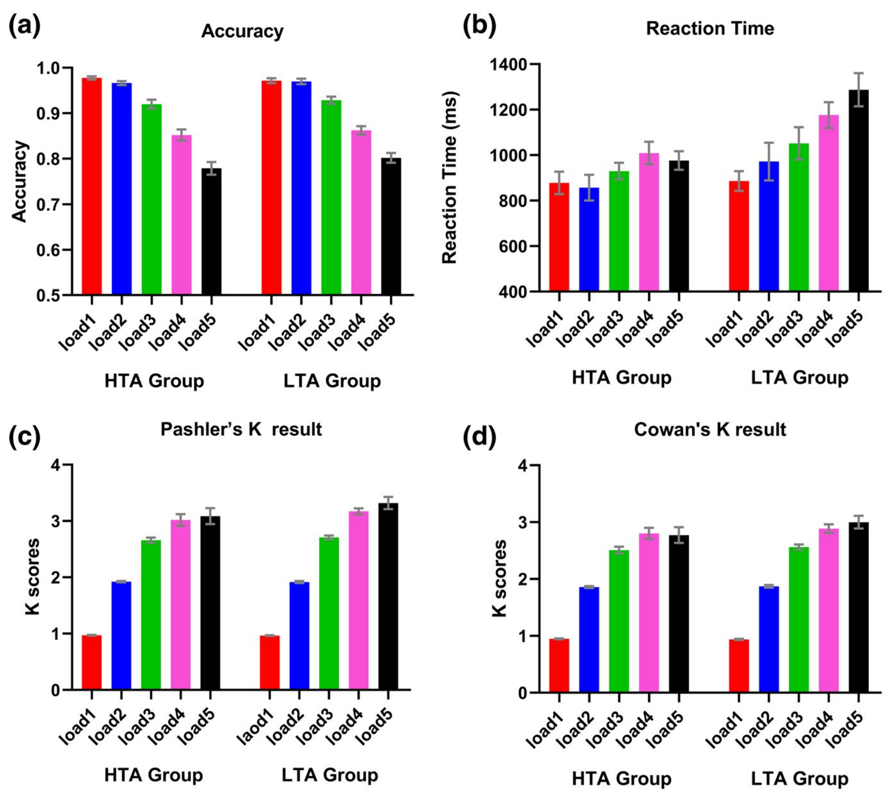

FIGURE 3 Behavioral result of the Task. (a) Accuracy of HTA and LTA groups both decreased with load, with lower accuracy under high load conditions. (b) The reaction time of the HTA group did not significantly change with the load but that of the LTA group increased with the load. (c) The Pashler's K score of both LTA and HTA groups increased with the increase of load, but there was no significant difference in trends between the two groups. (d) The Cowan's K score showed the same trend with Pashler's K score. Error bars represent standard errors of the means. HTA, high test anxiety; LTA, low test anxiety

3 | RESULTS

K score, Accuracy, Reaction times, and CDA amplitudes were analyzed using 2 (group: HTA or LTA) × 5 (condition: 1, 2, 3, 4, 5) repeated measures ANOVA. We conducted the ANOVA with the Pashler K score (Figure 3c) and observed a significant main effect of condition, $F(4,176) = 497.12$, $p < .01$, $\eta_p^2 = 0.92$, $BF10 > 100$.

Significant differences were observed between conditions 1 and 2, 2 and 3, and 3 and 4 (all $p < .01$) but no difference between conditions 4 and 5 ($p = .08$). Neither the main effect of group nor the interaction effect of group and condition was significant $F(1,44) = 1.57$, $p = .22$, $\eta_p^2 = 0.04$, $BF10 = 0.39$ and $F(4,176) = 1.58$, $p = .22$, $\eta_p^2 = 0.04$, $BF10 = 0.34$. We found comparable results on the Cowan's K score. Analysis with the Cowan K score (Figure 3d) revealed a significant main effect of condition, $F(4,176) = 381.64$, $p < .01$, $\eta_p^2 = 0.89$, $BF10 > 100$. We discovered significant differences between conditions 1 and 2, 2 and 3, 3 and 4 (all $p < .01$), but no difference between conditions 4 and 5 ($p = .49$). Neither the main effect of group nor the interaction effect of group and condition was significant $F(1,44) = 1.01$, $p = .32$, $\eta_p^2 = 0.02$, $BF10 = 0.31$ and $F(4,176) = 1.23$, $p = .29$, $\eta_p^2 = 0.03$, $BF10 = 0.19$.

For Accuracy (Figure 3a), the main effect of condition was significant, $F(4,176) = 296.20$, $p < .01$, $\eta_p^2 = 0.87$, $BF10 > 100$. Significant differences were observed between conditions 2 and 3, 3 and 4, and 4 and 5 (all $p < .01$) but no difference between conditions 1 and 2 ($p = .21$). Neither the main effect of group nor the interaction effect of group and condition was significant $F(1,44) = 0.63$, $p = .43$, $\eta_p^2 = 0.01$, $BF10 = 0.32$ and $F(4,176) = 1.36$, $p = .26$, $\eta_p^2 = 0.03$, $BF10 = 0.24$.

With reaction time for correct trials (Figure 3b), the interaction effect between group and condition was significant, $F(4,176) = 2.85$, $p = .03$, $\eta_p^2 = 0.06$, $BF10 = 4.92$. Simple effect analysis of the HTA group revealed no difference between conditions (all $p > .27$). In the LTA group, significant difference was observed between low and high load conditions (condition 1 vs. 4 ($p < .01$), condition 1 vs. 5 ($p < .001$), condition 2 vs. 5 ($p < .001$), and condition 3 vs. 5 ($p < .01$)). The HTA group's reaction time did not change with load, but the LTA group's reaction time increased with load. Significant main effects of group and condition were observed, $F(1,44) = 6.68$, $p = .01$, $\eta_p^2 = 0.13$, $BF10 = 6.51$ and $F(4,176) = 11.17$, $p < .01$, $\eta_p^2 = 0.20$, $BF10 > 100$, respectively. Significant differences were observed in the reaction times for conditions 4 ($p = .032$) and 5 ($p < .001$), and reaction time is longer in the LTA group. However, no difference was observed between the HTA and LTA groups in conditions 1 ($p = .90$), 2 ($p = .26$), and 3 ($p = .13$).

K scores reflect effectiveness, but EEG data reflect efficiency. Anxiety influences efficiency more than it influences effectiveness. CDA is a negative wave of continuous activity during the maintenance stage. Therefore, we considered the EEG data more closely (Figure 4). We employed the same design to assess CDA amplitude (400–900 ms) and observed significant interaction effects between group and conditions, $F(4,176) = 2.59$, $p = .04$, $\eta_p^2 = 0.06$, $BF10 = 3.72$. Simple effect analysis of the HTA group revealed no difference between conditions 3 and 4 and 4 and 5 but a significant difference between conditions 1 and 2 ($p < .01$) and 2 and 3 ($p < .01$). The working memory capacity of the HTA group was 3. In the LTA group, no significant difference was observed between conditions 4 and 5, or 2 and 3, but a significant difference was observed between conditions 1 and 2 ($p < .001$) and 3 and 4 ($p < .001$). The working memory capacity of the LTA group was 4. Significant main effects of group and condition were observed, $F(1,44) = 7.24$, $p < .01$, $\eta_p^2 = 0.14$, $BF10 = 6.98$, and $F(4,176) = 79.07$, $p < .01$, $\eta_p^2 = 0.64$, $BF10 > 100$, respectively. Furthermore, significant differences were observed among conditions 1 and 2, 2 and 3, and 3 and 4 (all $p < .01$). Significant differences were observed in the CDA amplitude of load 2 ($p = .026$), load 4 ($p = .006$), and load 5 ($p = .005$) in the HTA and LTA groups, but there was no difference at load 1 ($p = .49$) and load 3 ($p = .23$).

Finally, we conducted correlation analysis between the K score and CDA amplitude (Figure 5). We calculated Pashler's K score difference between load 1 and load 5. The difference score was correlated with load 2's CDA amplitude in the LTA group, $r(22) = .45$, $p = .03$, but not in the HTA group $r(24) = .09$, $p = .69$.

4 | DISCUSSION

This study used the CDT to assess the influence of test anxiety on working memory capacity. The results indicated that the K scores of the HTA and LTA groups increased with the number of stimuli. However, no differences were observed in the K scores of the two groups under any condition. The CDA amplitude of the HTA group did not increase after load 3, and that of the LTA group did not increase after load 4. Moreover, the CDA amplitudes of the LTA group were higher than that of the HTA group under conditions 2, 4, and 5. The reaction time of the LTA group increased with the task load but decreased under high-load conditions in the HTA group.

In the experimental stage, we observed differences in visual working memory between the HTA and LTA groups. The CDA amplitudes increased (i.e., increasingly negative) with the number of items encoded in the working memory, and no further increase was observed when working memory capacity was reached. The CDA results indicated that the amplitudes of the HTA and LTA group

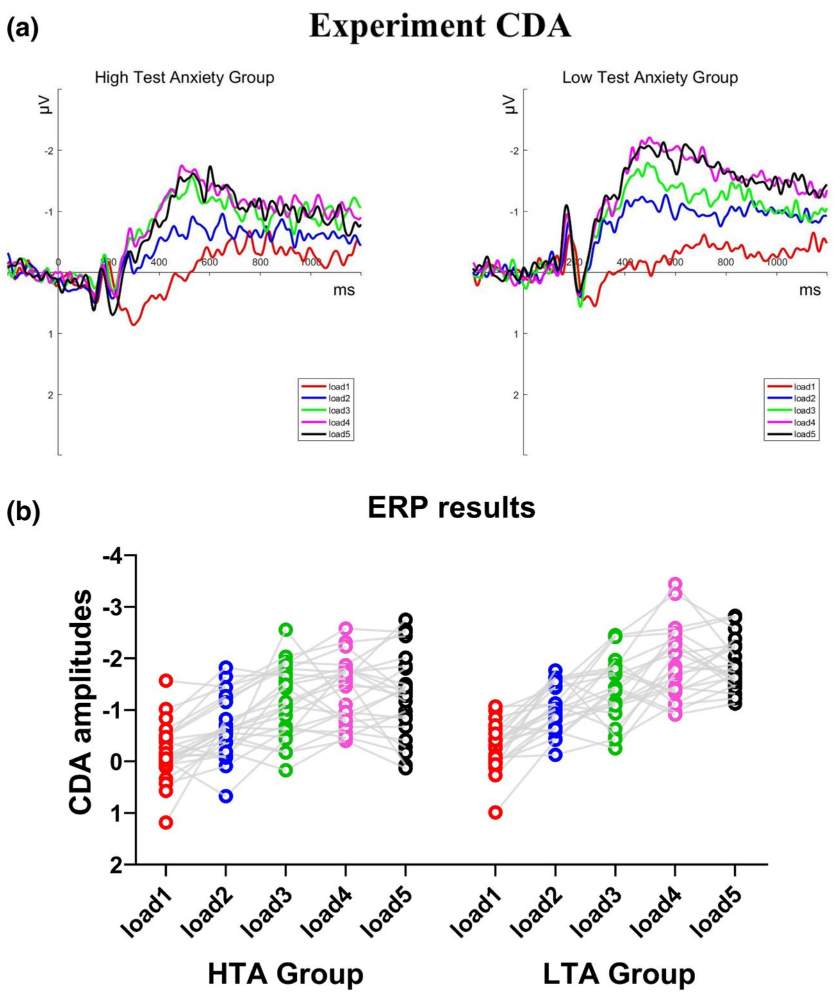

FIGURE 4 CDA results of the task. (a) The red, blue, green, pink, and black lines indicate conditions 1, 2, 3, 4, and 5, respectively. In the HTA group, the CDA amplitude did not increase after condition 3 (green line). In the LTA group, the CDA amplitude did not increase after condition 4 (pink line). The CDA amplitude indicated that the working memory capacity of the HTA group was 3 and that of the LTA group was 4. (b) Line chart of two groups' CDA amplitudes. The CDA amplitudes of the HTA and LTA groups showed different patterns under high load conditions (especially loads 3 and 4). Each gray line represents one participant. CDA, contralateral delay activity; ERP, event-related potential; HTA, high test anxiety; LTA, low test anxiety

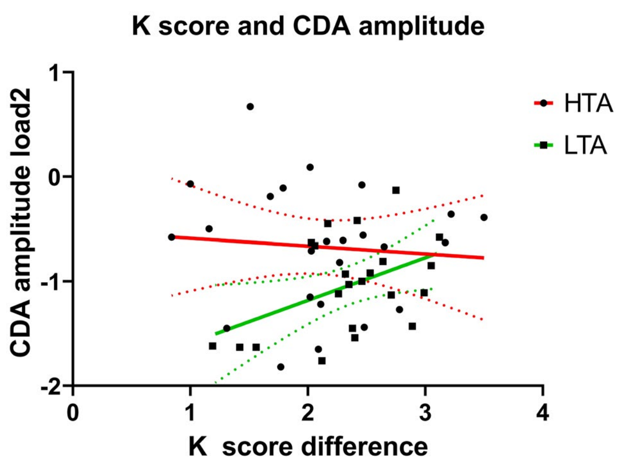

FIGURE 5 Correlation between K score difference and CDA amplitude in the LTA group, but not in the HTA group. CDA, contralateral delay activity; HTA, high test anxiety; LTA, low test anxiety

reached the asymptote at three and four target stimuli, respectively, supporting previous research that has reported the reduced working memory capacity of individuals with High trait anxiey (Qi, Chen, et al., 2014). The working memory capacity of normal individuals is approximately 3–4 (Vogel et al., 2005), but these small differences are highly predictive of cognitive tasks including reading comprehension, mathematics, problem-solving, and academic performance (Jaeggi et al., 2014). Individuals with HTA typically exhibit poor academic performance as a result of their reduced working memory capacity. Furthermore, the working memory of the HTA group can be maintained and manipulated in the short term, the effect of which may negatively influence test anxiety in students.

We observed that under three conditions (loads 2, 4, and 5), the CDA amplitudes of the HTA group were low, indicating that the working memory of the HTA group was insufficient. The CDA amplitude relates to the differences in working memory tasks and is an effective indicator of differences between individuals (Luria et al., 2016; Vogel et al., 2005; Xu et al., 2018). (Adam et al., 2018) adopted a whole-reported CDT and observed that the CDA amplitudes were higher in high-task performance trials. Therefore, the difference in CDA amplitude under the same load condition supported the conclusion that the working memory of the HTA group was insufficient.

The division at load 3 reflected the activation of compensation strategies for HTA individuals and may represent a trait aspect that already began under lower load conditions (e.g., load 2) and reached their limit under high-load conditions (e.g., load 4).

However, no differences in K scores were noted between the HTA and LTA groups. The K score and CDA amplitude both describe information in working memory, with the K score being the estimation index at a behavioral level and the CDA amplitude being the neural index that tracks object information in real time (Shen et al., 2012). The separation between the K score and CDA amplitude in our experiment was consistent with related viewpoints on attentional control theory regarding anxiety (Eysenck & Derakshan, 2011; Eysenck et al., 2007). Studies have argued that the K score reflects processing effectiveness and that the CDA amplitude reflects processing efficiency (Qi, Chen, et al., 2014). According to attention control theory, anxiety impairs processing efficiency but not processing effectiveness, which was supported by our research.

The reaction time of the LTA group increased with the load. However, the reaction time of the HTA group only increased under low-load conditions and was reduced under high loads (loads 4 and 5). Many factors may affect reaction time. For example, motivation accelerates motor performance (Pessiglione et al., 2007). Our experiment required participants to respond as quickly and as accurately as possible. HTA group may have stronger motivation to complete the task under high load conditions, especially at loads 4 and 5. Our results supported findings from inhibition control tasks and structural equation model analysis about test anxiety. In an inhibitory control task, Wei et al. (2021) determined that HTA individuals tended to exhibit increased top–down attention control inhibition, and they can fail to compensate for inhibition when demands are high (Wei et al., 2021). Putwain and Symes (2018) employed structural equation method analysis and discovered that the compensation strategy of HTA individuals may not compensate for the negative effects of worry, indicating that the worry and task demands exceeded the supply of working memory resources (Putwain & Symes, 2018).

Test anxiety negatively predicts academic performance (von der Embse et al., 2018), whereas working memory capacity positively predicts academic performance (Finn et al., 2017; Jaeggi et al., 2014). Test anxiety is closely related to metacognition, the ability to access and control one's own cognitive processes. Veenman et al. (2000) asked participants to think aloud while solving math problems; the authors used systematical observation and thinking-aloud protocols to rate the participants' metacognitive skillfulness. The LTA group exhibited strong metacognitive skillfulness while solving math problems, and differences in metacognitive and math performance were related (Veenman et al., 2000). Metacognitive skillfulness is also related to average cumulative grade point average (Ward & Butler, 2019). In addition, Adam and Vogel (2017) analyzed trial-by-trial subjective ratings of inattention level in a whole-report visual working memory task, reporting that metacognitive monitoring may be key to working memory success. From a results-driven perspective, individuals with HTA may exhibit reduced working memory capacity (Adam & Vogel, 2017).

The reduced working memory capacity of the HTA group may be related to insufficient attention control ability (Adam et al., 2018; Shen et al., 2012; Vogel et al., 2005). Limited working memory capacity requires individuals to selectively process information in their environments. Vogel et al. (2005) divided participants into high and low working memory capacity groups according to behavioral data and observed that the CDA amplitude of the low working memory capacity group under the interference condition was equivalent to that under the multitarget condition. This result indicated that individuals with low working memory capacity cannot effectively filter interference stimuli. High working memory capacity individuals have high attention control ability, which is reflected in their management of emotional interference stimuli (Ye et al., 2018). Ye et al. (2018) adopted the emotional working memory paradigm to investigate individuals' filtering performance of emotional interference stimuli. They observed that the high working memory capacity group effectively filtered neutral and negative emotional stimuli. Zhang et al. (2019) observed test threat–related inhibitory control deficiency in individuals with test anxiety, supporting our findings on working memory capacity.

CDA may originate from the parietal cortex (van Dijk et al., 2010) and be distributed in the temporal, parietal, and occipital areas (Shen et al., 2012). Studies have demonstrated that the successful representation of working memory in the parietal cortex is related to the activation of the prefrontal lobe. In turn, the prefrontal lobe plays a vital role in the production of the CDA component (Voytek & Knight, 2010). Therefore, the CDA results of individuals with HTA in this study may reflect impaired prefrontal activation. In a resting state, individuals with HTA have higher alpha energy (Ward et al., 2017), which is closely related to visual working memory (Bonnefond & Jensen, 2012; Eriksson et al., 2015). This indicates that the working memory deficiency of HTA individuals may be related to the energy of the alpha band. In conclusion, HTA individuals exhibit reduced working memory capacity represented by their CDA amplitudes, which reflects reduced processing efficiency.

This study has several limitations. First, eye drift bias toward the attended side of the screen could influence the experiment that was presented on both sides. We were aware of this potential bias and thus strictly emphasized the need for eye fixation in the instructions. After completing the experiment, all participants self-reported that they maintained eye fixation during the task. We could not calculate the differences in amplitude between the cued and uncued as Xie and Zhang (2018) did to provide objective physiological measurement of the eye drift bias. More technical methods may be adopted to control eye drift bias in the future. Second, regarding the experimental stimuli, we used neutral color squares to explore the general working memory capacity characteristics of HTA individuals. Threatening stimuli can be employed in future work to further explore HTA individuals' working memory (Berggren & Eimer, 2021; Stout et al., 2013; Ward et al., 2021). Third, the relationship between test anxiety and working memory capacity remains unclear. More intervention methods may be introduced in future research to explore the causal relationship between the two variables. With a deeper understanding of the influence mechanism of test anxiety, we can identify practical techniques to alleviate its negative influence. Future research should adopt more cognitive tasks to thoroughly reveal the negative effects of test anxiety. As shown by the findings of the present study, working memory training provides a promising direction to relieve the negative effects of test anxiety.

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AUTHOR CONTRIBUTIONS

Jintao Song: Data curation; Methodology; Software; Validation; Visualization; Writing-original draft. **Lei Chang:** Writing-review & editing. **Renlai Zhou:** Conceptualization; Formal analysis; Funding acquisition; Investigation; Methodology; Project administration; Resources; Supervision; Validation; Visualization; Writing-review & editing.

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