Journal of Affective Disorders 292 (2021) 700–707

Contents lists available at ScienceDirect

Journal of Affective Disorders

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

Research paper

Test anxiety impairs filtering ability in visual working memory: Evidence from event-related potentials

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ARTICLE INFO

Keywords:
Test anxiety
Working memory
CDA amplitude
K score
ERPs

ABSTRACT

Attentional control theory regards individuals with high anxiety as having deficits of inhibitory control when faced with distractors, especially under high-load conditions and with threatening distractors. Research on test anxiety has a long history, but the working memory (WM) characteristics of individuals with high test anxiety (HTA) remain unclear. We used two experiments to test the WM filtering ability of individuals with HTA, and the salient results were those of the contralateral delay activity amplitude rather than K score. The first experiment employed neutral distractors. HTA participants filtered distractors under low-load conditions but not under high-load conditions. Participants with low test anxiety (LTA) filtered distractors under high-load conditions but not under low-load conditions. The second experiment utilized threatening distractors. The participants with HTA exhibited deficits in their ability to filter neutral and threatening distractors, whereas the participants with LTA filtered both types of distractor.

Test anxiety refers to the anxiety symptoms individuals experience when regarding tests as threats (Zeidner, 1998). A meta-analysis discovered the prevalence of test anxiety among Chinese students to be approximately 22.32% (Huang and Zhou, 2019), and multiple other studies have found the prevalence to be approximately 20% (D. Putwain and Daly, 2014). Previous studies find that test anxiety individuals have attention (Dong et al., 2017) and inhibition control problem (Hua Wei et al., 2021; H. Wei et al., 2020; W. Zhang et al., 2019), pointing to the potential working memory deficits. Attention Control Theory also states that test anxiety mainly impairs working memory (Michael W. Eysenck and Derakshan, 2011; M. W. Eysenck et al., 2007). Therefore, we focused on test anxiety individuals' working memory, core executive function of individual (Diamond, 2013) .

The WM is the human brain's ability to store and manipulate information quickly (A. Baddeley, 2003; Cowan, 2001; Eriksson et al., 2015). The WM comprises two main complementary aspects: WM capacity and WM filtering (Qi et al., 2014; Stout et al., 2013; Vogel et al., 2005). People often must simultaneously process large amounts of visual information. However, visual WM capacity is limited. The WM can simultaneously maintain only three or four simple objects, along with their color and orientation (Cowan, 2001; Vogel et al., 2005). Moreover, distractors can additionally burden the WM. The precious working memory resource require individuals to establish efficient information choose mechanism to incorporate information highly relevant to the task and avoid capacity wasted by the distractors. Researchers (Vogel et al., 2005) named the ability filtering efficiency (FE), filtering distractors not related to the task goal. The WM's ability to cope with distractors does not simply complement target encoding but constitutes an independent and essential function (Wyatt and Machado, 2013). Some scholars have even posited that the key factor distinguishing high and low WM performance is distractor suppression rather than target activation (Zanto and Gazzaley, 2009). Therefore, our research focused on the WM filtering of individuals with HTA.

Attentional control theory can be used to describe the impact of anxiety on cognitive tasks (Michael W. Eysenck and Derakshan, 2011; M. W. Eysenck et al., 2007). The theory assumes that individuals with high anxiety have deficits in distractor filtering, and such deficits are exacerbated under high-load conditions. Using a change detection task (CDT) performed by individuals with high anxiety, Qi et al. (2014) discovered that the contralateral delay activity (CDA) amplitude under a condition with distractors was equivalent to that under a multitarget condition, indicating that individuals with high anxiety cannot effectively filter neutral distractors. Stout and colleagues (Stout et al., 2015; Stout et al., 2013) have experimented with threatening distractors and

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https://doi.org/10.1016/j.jad.2021.05.091
Received 6 January 2021; Received in revised form 19 March 2021; Accepted 31 May 2021

revealed that individuals with high anxiety can filter neutral distractors and struggle to filter only threatening distractors. The aforementioned studies reached different conclusions regarding how individuals with high anxiety filter neutral distractors because they adopted different research paradigms. Qi et al. (2014) required participants to remember the orientations of two or more rectangular bars, whereas Stout and colleagues required participants to remember one or more facial stimuli (Stout et al., 2015, 2013). The perceptual loads of these experiments differed, and thus, the WM resources required to process the two types of stimulus cannot be directly compared. Therefore, a single type of stimulus and more load conditions should be used for further study.

Individuals with HTA show attentional bias toward threatening stimuli and easily notice threatening cues in their environment (Dong et al., 2017; Keogh and French, 2001; David W. Putwain et al., 2020; H. Zhang et al., 2015). Such attentional bias can unnecessarily allow threatening information to invade the WM and interfere with the current task (Schweizer et al., 2019). Threatening stimuli in the WM not only compete for cognitive resources in the perceptual processing stage but also affect the attentional control stage (Alan Baddeley, 2013; Barrett et al., 2004; Okon-Singer et al., 2015; Pessoa, 2009). Emotion regulation through the filtering of irrelevant negative information from the WM is critical to mental health (Qi et al., 2014; Stout et al., 2015). We hypothesized that individuals with HTA are more easily distracted by threatening test-related stimuli than by neutral stimuli.

CDTs have been widely used in WM research (Qi et al., 2014, 2014; Stout et al., 2013; Vogel et al., 2005). Researchers have used the contralateral control method to eliminate factors unrelated to memory load and then obtain the K score and CDA amplitude. A CDT can also be used measure filtering ability (Qi et al., 2014; Stout et al., 2013; Vogel et al., 2005). If a participant fails to filter distractors in a CDT with two targets and two distractors, the number of items stored in the WM will be equivalent to that under a four-target condition. If the distractors are filtered, the K score and CDA amplitude will be equivalent to those under a two-target condition. K scores reflect the filtering results at the behavioral level, while the CDA amplitudes reflect the time course of filtering during the working memory maintenance stage. We can comprehensively describe the characteristics of the working memory filtering ability through the combination of the two indicators.

Attentional control theory regards anxiety as impairing processing efficiency but not processing effectiveness (Michael W. Eysenck and Derakshan, 2011; M. W. Eysenck et al., 2007). Individuals with HTA can adopt a series of compensation strategies to still process stimuli effectively. Researchers demonstrated that anxiety has little influence on behavior and more influence on neural processing (Qi et al., 2014). We assumed that test anxiety impairs processing efficiency, which is reflected by the CDA amplitude rather than the K score. On the basis of the preceding theoretical background, we investigated the WM filtering ability of individuals with HTA. We employed multiple neutral loads in Experiment 1 and threatening test-related stimuli in Experiment 2 and used K score and CDA amplitude to evaluate participants' ability to filter neutral and threatening stimuli.

Experiment 1

Measurement instruments

For Experiment 1, we adopted Sarason's (Sarason, 1978) Test Anxiety Scale (TAS). The TAS comprises 37 questions, and each question has two options: *yes*, worth 1 point, and *no*, worth 0 points. A TAS score of $\geq$20 was considered HTA, and a TAS score of $\leq$12 was considered low test anxiety (LTA). The test–retest reliability coefficient of the TAS is 0.61, and the homogeneity coefficient was found to be 0.64 in China (Wang, 2001). We also employed the Test Anxiety Inventory (TAI) to measure test anxiety. Test Anxiety Inventory includes 20 questions, each question can be 1∼4 points, the total score ranges from 20 to 80. The higher the score, the higher the test anxiety level.

Participants

Advertisements were posted in a Nanjing University online recruitment forum. In total, we selected 20 participants for the HTA group (4 men/16 women, average age of 21.6 years) and 20 participants for the LTA group (4 men/16 women, average age of 20.5 years). The TAS scores (HTA: 27.15 ± 3.84, LTA: 9.05 ± 2.28) and TAI scores (HTA: 14.20 ± 3.02, LTA: 7.55 ± 1.28) of the two groups differed significantly, $t(38) = 18.11$, $p < .001$ and $t(38) = 9.07$, $p < .001$, respectively. However, age did not differ significantly between groups, $t(38) = 1.81$, $p = .08$. All of the participants were right handed and signed an informed consent form before the experiment.

Neutral WM task

We employed a CDT with neutral distractors for the first experiment (Qi et al., 2014; Vogel et al., 2005). The task required participants to report a change only when the orientation of a red target changed. During the experiment, the participants were asked remain fixated on a point in the center of a screen to reduce horizontal eye movement. The viewing angle for the unilateral memory item was $4^\circ \times 7.6^\circ$ The angle from the left and right memory items to the central fixation point was 2.8° The numbers of rectangular bars on the left and right sides and the types of stimuli were the same. We employed four rectangular bar orientations: horizontal, vertical, 45° left, and 45° right. Red (RGB: 200, 0, 0) was used for the target, and green (RGB: 25, 255, 52) was used for the distractor. In each trial, memory cues to the right and left were presented for 200 ms in a ratio of 1:1. Subsequently, a 200–400-ms random window was presented. Then, the memory items were displayed for 100 ms before disappearing. The participants were required to retain the memory items in their WM for 900 ms. Finally, probes were presented for 3000 ms. The interval between trials was 2000 ms. In total, the experiment comprised 10 blocks of 80 trials each. The entire experiment took approximately 1.5 h. A flowchart of this trial is presented in Fig. 1.

Electroencephalography

Neuroscan 64-channel electroencephalography (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 also 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 placed on the sides of both eyes recorded 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 $\leq$10 kΩ. During offline analysis, the sampling frequency was reduced to 500 Hz, and a 0.1–30-Hz bandpass was used for filtering. The average value of M1 and M2 was used as a reference.

K score and CDA amplitude analysis

The two main methods of calculating K score are the Pashler—$K = N \times (HR - FA)/(1 - FA)$—and Cowan—$K = N \times (HR - FA)$—methods. In this formulae, K is the WM capacity, and N is the number of items that must be memorized. HR is the hit rate, or the probability of correctly identifying a change. FA is the false alarm rate, or the probability of incorrectly responding to no change.

Analysis of event-related potentials (ERPs) used data from 200 ms before the stimulus onset as the baseline. The CDA amplitude is the difference between the contralateral and ipsilateral waves. 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

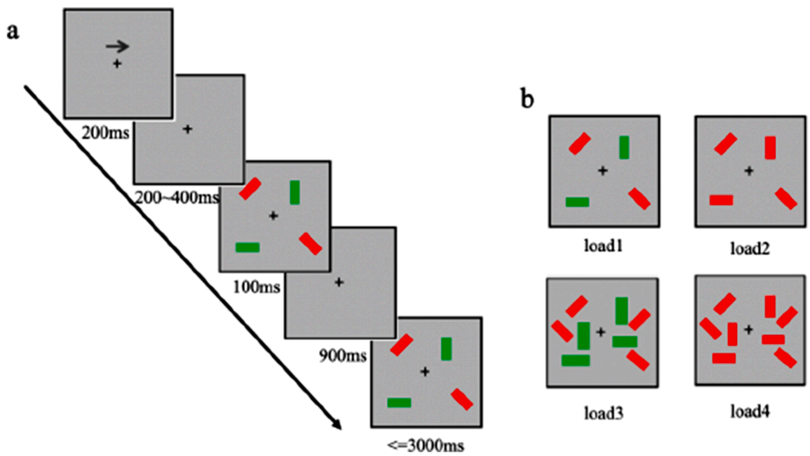

Fig. 1. Neutral WM task.
The four trial conditions are depicted in the figure. (a) load1: 1T + 1D, load2: 2T, load3: 2T + 2D, load 4: 4T. (b) Cue: 200 ms, random window: 200–400 ms, memory stimulus: 100 ms, delay window: 900 ms, probe: until response. Participants were required to remember only the targets on the right side, and this requirement was necessary to isolate the CDA. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

posterior brain area when the memory item was on the right. One of the important starting points of our current work was to discover the difference between test anxiety and other anxiety subtypes in the dimension of working memory. Therefore, the selection of channels and time window in current experiment referred to the previous research about trait anxiety and adopted the same channels (Qi et al., 2014, and Li 2014).We selected five mastoid pairs (P3 and P4, P5 and P6, P7 and P8, PO3 and PO4, and PO7 and PO8) for calculating CDA (Qi et al., 2014, 2014). We performed Greenhouse–Geisser correction of p values for statistical analysis and employed Bonferroni correction for comparison between conditions.

There was no difference in the number of trials in experiment 1 saved between the HTA group ($M = 697.85$, $SD = 48.49$) and LTA group ($M = 675.85$, $SD = 62.73$), $t(38) = 1.27$, $p = 0.21$, and further no difference in each condition ($Ps > 0.18$). The remaining number trials in each condition of LTA group load1 (1T + 1D): 178.95 ± 14.88; load2 (2T): 178.80 ± 16.65; load3 (2T + 2D): 165.10 ± 15.47; load 4 (4T): 152.50 ± 19.17. The remaining number trials in each condition of HTA group load1 (1T + 1D): 184.95 ± 13.07; load2 (2T): 184.10 ± 13.21; load3 (2T + 2D): 169.60 ± 11.69; load 4 (4T): 159.20 ± 15.09.

Results

K scores, reaction times, and CDA amplitudes were analyzed using 2 (group: HTA or LTA) × 4 (conditions: 1T + 1D, 2T, 2T + 2D, or 4T) repeated measures analysis of variance (ANOVA). Analysis using the Cowan K score revealed a significant main effect of condition, $F(3, 114) = 302.56$, $p < .001$, $\eta_p^2 = 0.89$, $BF10 > 100$. We discovered significant differences between 1T + 1D and 2T ($p < .001$), 2T and 2T + 2D ($p < .001$), 2T + 2D and 4T ($p < .001$). The main effect of group was nonsignificant, $F(1, 38) = 0.14$, $p = .71$, $\eta_p^2 = 0.004$, $BF10 = 0.22$. The interaction effect of group and condition was nonsignificant, $F(3, 114) = 0.45$, $p = .54$, $\eta_p^2 = 0.01$, $BF10 = 0.09$. To confirm the Cowan K score results, we conducted the same ANOVA with the Pashler K score and discovered a significant main effect of condition, $F(3, 114) = 393.75$, $p < .001$, $\eta_p^2 = 0.91$, $BF10 > 100$. We discovered significant differences between 1T + 1D and 2T ($p < .001$), 2T and 2T + 2D ($p < .001$), and 2T+2D and 4T ($p < .001$). Neither the main effect of group nor the interaction effect of group and condition was significant, $F(1, 38) = 0.65$, $p = .43$, $\eta_p^2 = 0.02$, $BF10 = 0.28$ and $F(3, 114) = 1.37$, $p = .25$, $\eta_p^2 = 0.04$, $BF10 = 0.29$, respectively.

We found a significant main effect of condition for reaction time, $F(3, 114) = 56.95$, $p < .001$, $\eta_p^2 = 0.60$, $BF10 > 100$. Significant differences were discovered between 1T+1D and 2T ($p = .02$), 2T and 2T + 2D ($p < .001$), and 2T + 2D and 4T ($p < .001$). Neither the main effect of group nor the interaction effect of group and condition was significant, $F(1, 38) = 0.67$, $p = .42$, $\eta_p^2 = 0.02$, $BF10 = 0.58$ and $F(3, 114) = 1.09$, $p = .33$, $\eta_p^2 = 0.03$, $BF10 = 0.36$, respectively.

K scores reflect effectiveness, but EEG data reflect efficiency. Anxiety influences efficiency more than it does effectiveness. Therefore, we considered the EEG data more closely (Fig. 2) We employed the same design to assess CDA amplitude (400–900 ms) and found the interaction effect between group and conditions was significant, $F(3, 144) = 3.08$, $p = .04$, $\eta_p^2 = 0.08$, $BF10 = 5.33$. A simple effect analysis of the HTA group revealed no difference between 2T+2D and 4T ($p = 1.00$) but a significant difference between 1T+1D and 2T ($p < .01$). In the LTA group, a significant difference was found between 2T+2D and 4T ($p < .01$), but no significant difference was discovered between 1T+1D and 2T ($p = .95$). We found significant main effects of group and condition, $F(1, 38) = 4.18$, $p = .04$, $\eta_p^2 = 0.09$, $BF10 = 3.55$ and $F(3, 114) = 26.53$, $p < .001$, $\eta_p^2 = 0.41$, $BF10 > 100$, respectively. We also detected significant differences between 1T + 1D and 2T ($p = .007$, $BF10 = 7.19$), 2T and 2T + 2D ($p = .007$, $BF10 > 100$), and 2T + 2D and 4T ($p = .037$, $BF10 = 1.75$).

Experiment 2

Participants

We recruited participants for Experiment 2 in the same manner as we did for Experiment 1. According to TAS scores, we selected 20 participants for the HTA group (8 men/12 women, average age of 19.5 years) and 20 participants for the LTA group (7 men/13 women, average age of 20.4 years). The two groups' TAS scores (HTA: 24.45 ± 3.76, LTA: 9.00 ± 2.53) and TAI scores (HTA: 43.95 ± 7.29, LTA: 25.05 ± 2.48) were significantly different, $t(38) = 15.23$, $p < .001$ and $t(38) = 10.97$, $p < .001$, respectively. However, the ages of the two groups did not differ significantly, $t(38) = 1.55$, $p = .13$.

Emotional WM task

For Experiment 2, we adopted a CDT with both neutral and threatening distractors (Stout et al., 2015; Stout et al., 2013; Ye et al., 2018). We used a red box as the target stimulus and a yellow box as the distractor and employed seven experimental conditions: one neutral target (1NT), one threatening target (1TT), one neutral target and one threatening target (1NT + 1TT), two threatening targets (2TT), two neutral targets (2NT), one neutral target and one threatening distractor (1NT + 1TD), and one neutral target and one neutral distractor (1NT + 1ND). We conducted 200 trials under each condition. The ratio of changing to unchanging targets was 1:1. The interval between trials was 2000 ms. The experiment comprised 14 blocks of 100 trials each. The total duration of the experiment was approximately 2 h. In each trial, a

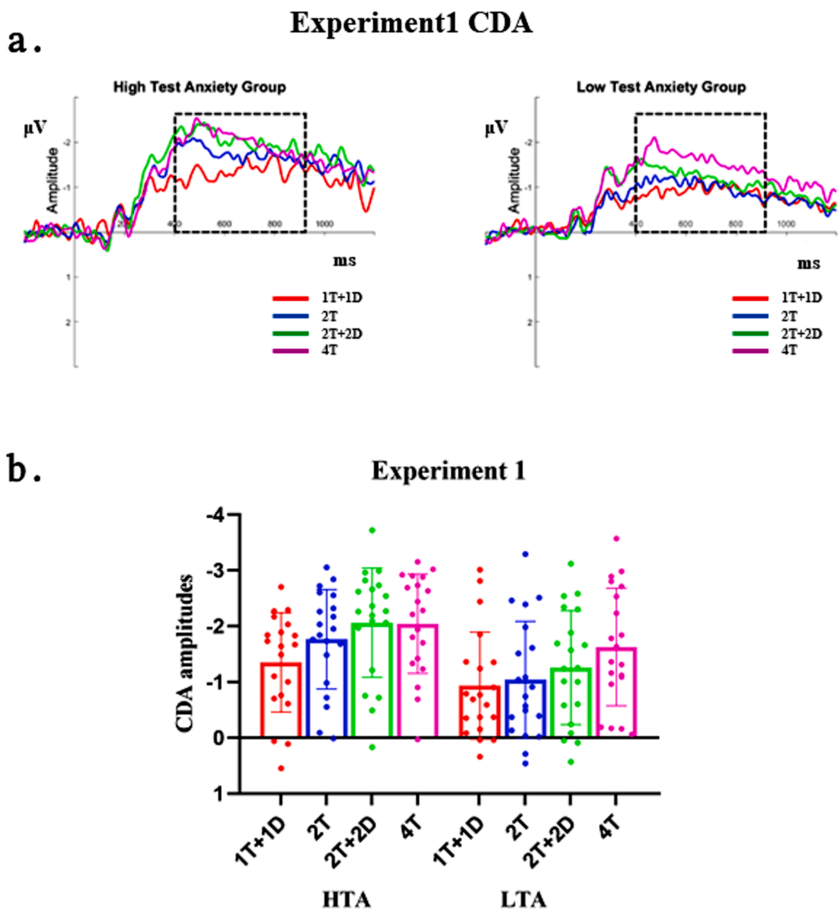

Fig. 2. ERP results of neutral WM tasks.
(a) The red line represents the 1T + 1D condition, the blue line represents 2T, the green line represents 2T + 2D, and the pink line represents 4T. The HTA group filtered distractors inefficiently under high-load conditions (green and pink), and the LTA group processed the distractors under low-load conditions (red and blue). (b) The results of the CDA amplitudes for the HTA (left) and LTA (right) group in the conditions separately. Bars show mean CDA amplitude and error bars depict standard error. Each dot represents the CDA amplitude of one participant in one condition. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

memory cue was first presented for 200 ms. After a 200–400-ms random window, the memory stimuli were presented for 500 ms. Next came the memory period for 900 ms. Then, probes were presented until the participants responded. The experiment required the participants to remember the target while fixating on central point. The specific sequences of stimulus presentation are illustrated in Fig. 3.

We selected 26 neutral pictures and threatening test-related pictures from a library of test anxiety pictures (Yu et al., 2011). The two types of stimulus differed significantly (Table 1) in relevance ($p < .001$), pleasure ($p < .001$), and dominance ($p < .001$).

Table 1
Scores (mean + standard deviation) of stimulus material characteristics in Experiment 2.

	Relevance	Pleasure	Dominance
Threatening	2.67(0.10)	5.12(0.52)	3.53(0.39)
Neutral	1.39(0.13)	4.07(1.39)	5.54(0.92)

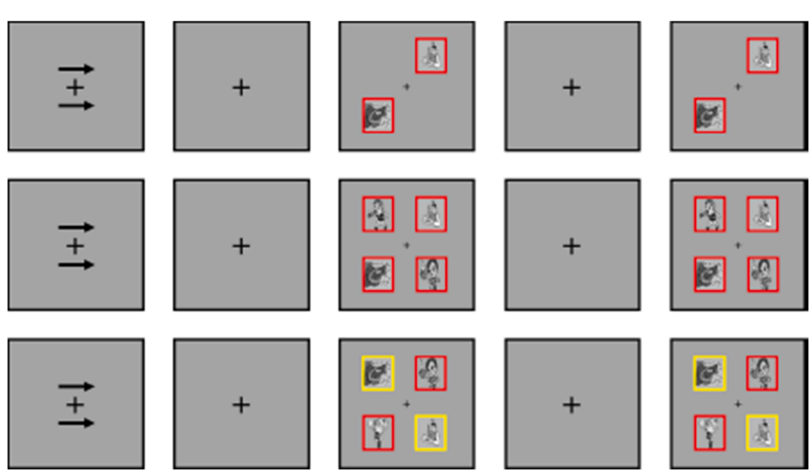

Fig. 3. Emotional WM task.
Three conditions are depicted from top to bottom: 1T, 2T, and 1T + 1D. The display sequence is illustrated from left to right. Cue: 200 ms, random window: 200–400 ms, memory stimulus: 500 ms, delay window: 900 ms, probe: until response.

Data analysis

We employed the same method for collecting EEG data as we did for Experiment 1, and we again calculated Cowan K scores. We also analyzed CDA in the same manner. The selection of channels in Experiment 2 was to maintain the consistency of our two experiment, so the same channels were selected. Regarding the time window, we chose a later time window relative to the stimulus onset because working memory is active during the whole maintenance stage, and filters distractors after a period should show more difference between the HTA and LTA groups.

There was no difference in the number of trials in Experiment 2 saved between the HTA group ($M = 808.60$, $SD = 99.38$) and LTA group ($M = 824.30$, $SD = 49.65$), $t\,(38) = 0.63$, $p = .53$, and further no difference in each condition ($Ps > 0.33$). The remaining number trials in each condition of LTA group condition1 (1NT):165.55 ± 11.63; condition 2 (1NT + 1NT):166.05 ± 11.13; condition 3 (1NT + 1TT):165.15 ± 10.11; condition 4 (1NT + 1ND): 164.50 ± 11.40; condition 5 (1NT + 1TD): 163.05 ± 10.84 . The remaining number trials in each condition of HTA group condition1 (1NT):163 ± 20.81; condition 2 (1NT + 1NT): 160.80 ± 20.91; condition 3 (1NT + 1TT): 163.65 ± 20.81; condition 4 (1NT + 1ND): 160.20 ± 20.57; condition 5 (1NT + 1TD):160.95 ± 19.19.

Results

K scores, reaction times, and CDA amplitudes were analyzed using 2 (group: HTA or LTA) × 5 (condition: 1NT, 1NT + 1NT, 1NT + 1TT, 1NT + 1ND, or 1NT + 1TD) repeated measures ANOVA. Analysis using the Cowan K score revealed a significant main effect of condition, $F(4, 152) = 7034.79$, $p < .001$, $\eta_p^2 = 0.99$, $BF10 > 100$. We found significant differences between 1NT and 1NT + 1NT ($p < .001$), 1NT and 1NT + 1TT ($p < .001$), 1NT and 1NT + 1ND ($p = .97$), 1NT and 1NT + 1TD ($p = .43$). The main effect of group was not significant, $F(1, 38) = 0.18$, $p = .68$, $\eta_p^2 = 0.005$, $BF10 = 0.34$. The interaction effect between group and condition was not significant, $F(4, 152) = 0.47$, $p = .76$, $\eta_p^2 = 0.01$, $BF10 = 0.12$.

For reaction time, the main effect of group was nonsignificant, $F(1, 38) = 0.04$, $p = .84$, $\eta_p^2 = 0.001$, $BF10 = 0.41$. The main effect of condition was nonsignificant, $F(4, 152) = 1.05$, $p = .38$, $\eta_p^2 = 0.03$, $BF10 = 0.25$. The interaction effect between group and condition was also nonsignificant, $F(4, 152) = 0.68$, $p = .60$, $\eta_p^2 = 0.02$, $BF10 = 0.25$.

For the same reason as Experiment 1, we paid closer attention to the EEG data (Fig. 4) For CDA amplitude (800–1200 ms), the interaction effect between group and condition was significant, $F(4, 152) = 2.55$, $p = .04$, $\eta_p^2 = 0.06$, $BF10 = 1.67$. Additional simple effect analysis revealed significant differences between the NT and NT + NT ($p < .001$), NT and

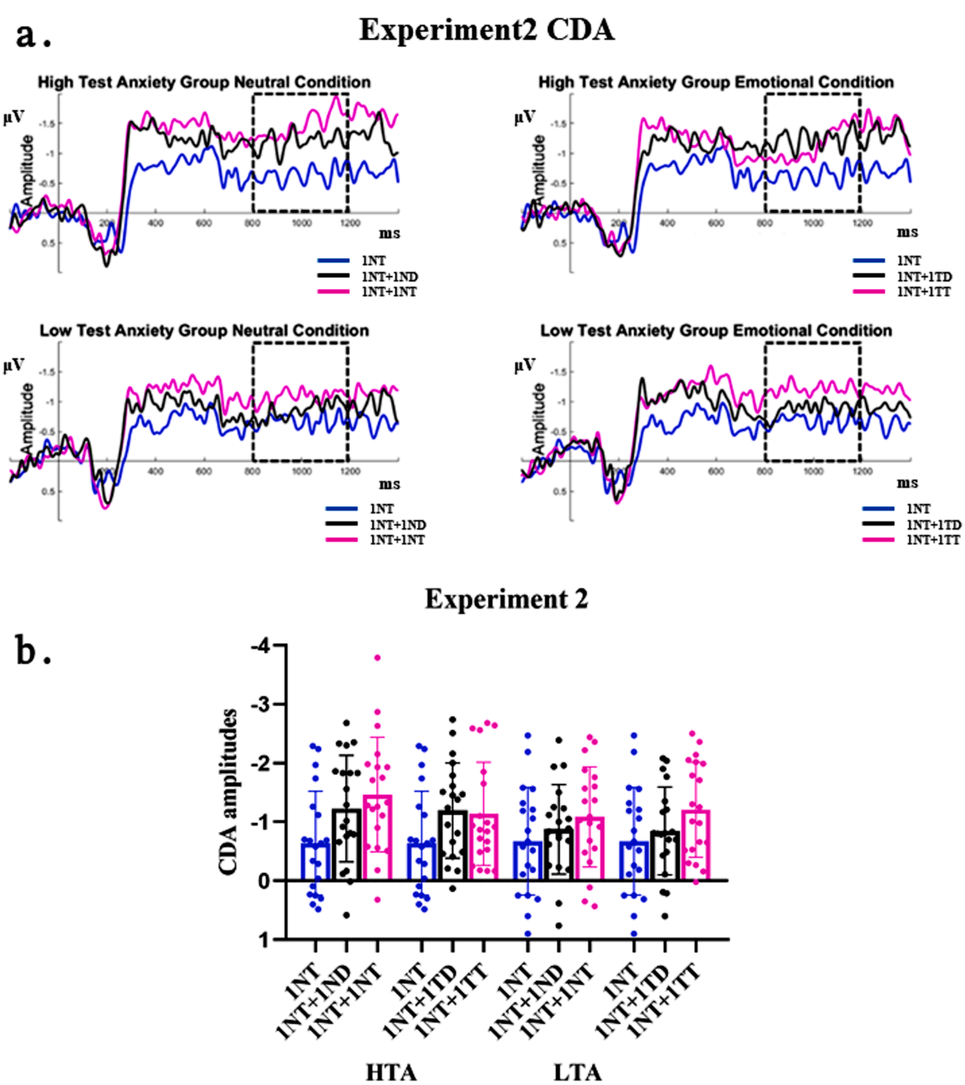

Fig. 4. ERP results of emotional WM tasks.
(a) The blue line represents the 1T condition, the pink line represents 2T, and the black line represents 1T + 1D. The HTA group processed both types of distractor, whereas the LTA group filtered the distractors. (b) The results of the CDA amplitudes for the HTA (left) and LTA (right) group in the conditions separately. Bars show mean CDA amplitude and error bars depict standard error. Each dot represents the CDA amplitude of one participant in one condition. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

NT + TT ($p = .011$), NT and NT + ND ($p = .002$), and NT and NT + TD ($p = .013$) conditions in the HTA group. In the LTA group, the differences between the NT and NT + NT ($p = .04$) conditions and between the NT and NT + TT conditions ($p = .005$) were significant, but no significant differences were discovered between the NT and NT + ND ($p = 1.00$) or NT and NT + TD ($p = 1.00$) conditions. The main effect of group was nonsignificant, $F(1, 38) = 0.67$, $p = .42$, $\eta_p^2 = 0.02$, $BF10 = 0.79$. The main effect of condition was significant, $F(4, 152) = 11.17$, $p < .001$, $\eta_p^2 = 0.23$, $BF10 > 100$. Furthermore, we found significant difference between 1NT and 1NT + 1NT ($p < .001$, $BF10 > 100$), 1NT and 1NT + 1TT ($p < .001$, $BF10 > 100$), 1NT and 1NT + 1ND ($p < .001$, $BF10 = 68.06$), 1NT and 1NT + 1TD ($p = .002$, $BF10 = 11.38$).

Discussion

We employed CDTs with neutral or neutral and threatening distractors to test the WM filtering ability of individuals with HTA. Our two experiments revealed no differences in the K scores of the HTA and LTA groups. Our salient findings are derived from CDA amplitude. In Experiment 1, the HTA group filtered distractors under low-load conditions but was affected by distractors under high-load conditions. The LTA group did not filter the distractors under low-load conditions but filtered them under high-load conditions. In Experiment 2, the HTA group demonstrated deficits in filtering both neutral and test-related distractors, whereas the LTA group filtered both types of distractor.

In Experiment 1, the HTA group was affected by distractors under high-load conditions. This result is consistent with that of a previous study on trait anxiety (Qi et al., 2014) and in line with attentional control theory (Michael W. Eysenck and Derakshan, 2011; M. W. Eysenck et al., 2007). However, our result differed in that the HTA group could filter distractors under low-load conditions. This result may be related to compensation strategies, the HTA group need to pay more resources to achieve the same task performance level as the LTA group. Under low-load conditions, individuals with HTA can adopt compensation strategies to filter distractors from their WM. However, as task demands increase, the sum of the additional resources required by the task and those required for the compensation strategy is excessive, and thus, individuals with HTA struggle to filter distractors. This result is supported by a recent study regarding test anxiety and compensation strategies (D. W. Putwain and Symes, 2018) that the cognitive load arise from the combination of worry and task maybe too high to be compensated.

The LTA group filtered distractors under high-load conditions but did not filter them under low-load conditions, reflecting the flexibility of individuals with LTA in allocating WM resources. CDA amplitude was demonstrated to reflect the WM load and degree of resources required by different objects (Salahub et al., 2019). CDA amplitude is related to task performance (Adam et al., 2018) and regulated by top-down attentional control (Gazzaley and Nobre, 2012; Sander et al., 2011). The participants with LTA did not filter the distracting stimuli from their WM when the task demand was low. As the task demand increased, the WM resources originally allocated to distractors under low demand were used to process the new target.

In Experiment 2, the HTA group's CDA amplitude under the condition with threatening test-related distractors was equivalent to that under a multitarget condition, indicating deficits among the HTA group in filtering such distractors. This result explains the difficulty individuals with HTA have in avoiding negative perceptions of tests (Chen and Zhou, 2010). As the two core components of executive function, WM and inhibitory control are closely related. Zhang et al. (W. Zhang et al., 2019) discovered that individuals with HTA exhibited inhibitory control deficits when performing both emotional (emotional Stroop) and cognitive (numerical Stroop) tasks, longer reaction time and difference in P2 component. Individuals with HTA fail to suppress the threatening distractors. Instead, they quickly notice, automatically process (P1, P2, and N2 components), and then further fine-process the threatening information (P3 component). This processing of threatening information stimulates negative emotion (LPP component). Such deficits in filtering threatening stimuli from the WM may also cause negative emotions to affect subsequent processing in individuals with HTA.

Inconsistent with Stout et al. (Stout et al., 2015, 2013) and our initial hypothesis that HTA group have more difficulty in filtering threatening distractors, we discovered that the HTA group also struggled to filter neutral distractors from the WM. While Qi et al.'s research do not include one distractor condition (Qi et al., 2014), we found that individuals with HTA filtered distractors under low-load conditions but exhibited filtering deficits under high-load conditions. We noticed that the HTA group had deficits in the filtering of both neutral and threatening distractors, in particular under high task loads. Thus, the individuals with HTA characteristically employed compensation strategies to filter distractors from their WM under low-load conditions. However, as the task load increased, they were more affected by distractors. Differences in WM encoding strategies are considered key factors explaining individual cognitive differences (Linke et al., 2011), and thus, filtering deficits may cause test anxiety.

The difference in working memory filtering ability between HTA & LTA group may be related to the difference in attention control ability. The highly limited working memory capacity requires individuals to selectively process information in the environment (Adam et al., 2018; Shen et al., 2012; Vogel et al., 2005). Vogel et al. (Vogel et al., 2005) divided the participants into high and low working memory capacity group according to the behavioral data, and it was found that the CDA amplitude of the low working memory capacity group under the distractor condition is equivalent to that under the multi-target condition, indicating that the individual cannot effectively filter the distractor. High working memory capacity individuals have higher attention control ability, which is also reflected when dealing with complex threatening distractors (C. Ye et al., 2018). Ye adopted the emotional working memory paradigm and investigated the performance of filtering emotional distractor stimuli. They found that the high working memory capacity group had better performance in filtering neutral and negative emotional stimuli. Through our current experiment, the relationship between filtering and capacity can be further obtained-Working memory filters certain types of stimuli effectively or not is affected both by stimulus-related and individual-related factors.

The main difference between the HTA and LTA groups was in their CDA amplitudes rather than their K scores. This distinction between K score and CDA amplitude results is consistent with attentional control theory (Michael W. Eysenck and Derakshan, 2011; M. W. Eysenck et al., 2007), which regards that anxiety impair processing efficiency rather than effectiveness. The K score is a behavioral estimation of the number of items retained in the WM, whereas CDA amplitude can track object information in the visual WM in real time (Shen et al., 2012). Previous studies have considered K score to reflect processing effectiveness and CDA amplitude to reflect processing efficiency (Qi et al., 2014). According to attentional control theory, anxiety impairs the efficiency, not the effectiveness, of processing. Thus, individuals with HTA should require more cognitive resources to achieve the same performance level as those with lower test anxiety. Our results support this conclusion.

Studies have demonstrated that the successful encoding of the WM in the parietal cortex is related to prefrontal lobe activation. The prefrontal lobe is crucial to CDA (Voytek and Knight, 2010). Therefore, our CDA results for the HTA group might reflect impaired prefrontal activation. Individuals with high anxiety have high alpha-band power in the resting state (Ward et al., 2017). The power of the alpha band is closely related to the visual WM (Bonnefond and Jensen, 2012; Eriksson et al., 2015) and, therefore, possibly related to the WM deficits in our HTA group. In conclusion, individuals with HTA exhibit deficits in WM filtering of both threatening test-related distractors and neutral distractors, and such deficits are reflected mainly by the CDA amplitude, not the K score.

Our research supports the specific division of anxiety in DSM-IV, which regards anxiety includes multiple subtypes (Qi et al., 2014, et al. 2014). We provided complete evidence that different anxiety subtype has own mechanism by demonstrating that Test Anxiety associated with unique Working Memory Filtering characteristics, still able to filter distractors under low-load conditions and exhibit deficits in filtering both neutral and threatening distractors. About the limitations of our work, we only provided evidence on the relevant level of Test Anxiety and Working Memory Filtering. In the next step, the causal relationship between the two variables should be explored through working memory training, or the transcranial direct current stimulation method to further explore the reasons of test anxiety form. There are also reasons to suspect that high test anxiety individuals have a higher level of depression or fear of negative evaluation than low test anxiety individuals. The group difference in the potential influence factors may partially cause the difference in behavioral and subclinical levels in our experiment (Rossignol et al., 2013, 2008; Chaoxiong Ye et al., 2020). Further studies should select high test anxiety or depression individuals more precisely, to thoroughly clarify the relationship between the two variables and their specific influence. And we only adopted simple orientations (experiment 1) and complex test threatening stimuli (experiment 2), more experimental stimulus materials should be adopted to verify our experimental results in future studies.

Contributors

J.S. and R.Z. designed the experiment. J.S. collected and analyzed the data. J.S., L.C., and R.Z. contributed to data interpretation. J.S., L.C., and R.Z. wrote the paper.

Role of the funding source

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

Declaration of competing interest

The authors declare no competing interests.

Acknowledgments

This study was supported by National Defense Science and Technology Innovation Special Zone Project of Logistics Support Department of the Central Military Commission (19-163-12-ZT-002-003-02).

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