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Electrophysiological and behavioral evidence for the attention capture and suppression failure of irrelevant singleton in test anxiety

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ABSTRACT

Attention bias (ABs) and inhibition deficits play crucial roles in the development, maintenance, and recurrence of test anxiety. However, whether test-anxious individuals will show ABs and inhibition deficits of general task-irrelevant stimuli in a complex visual display is unclear. Thus, we used the additional singleton task (AST) and recorded event-related potentials (ERPs) indices of attentional selection (the N2 posterior contralateral, N2pc), suppression (distractor positivity, PD), and maintenance of working memory (the sustained posterior contralateral negativity, SPCN) to explore this issue. Twenty-eight participants in the high test-anxious (HTA) group and twenty-eight participants in the low test-anxious (LTA) group attended the experiment and were required to search for a target and synchronously ignore a singleton distractor on some trials. Consequently, HTA and LTA individuals had poorer accuracies and longer response times in the distractor-present condition than in the distractor-absent condition. The HTA group got larger interferences from singleton distractors than the LTA group. Electrophysiological results revealed a distractor N2pc and SPCN in the HTA group. Moreover, target N2pc and SPCN in the HTA group were larger when the singleton distractor and target were on the same side than on the opposite side. These results indicated that HTA individuals were captured attention by singleton distractors and failed to expel them from working memory. Accordingly, the present findings extended previous work by providing direct evidence that test anxiety could increase the effects of stimulus-driven attention systems and impair the function of goal-directed attention systems.

1. Instruction

Test anxiety is an excessive fear or worry of poor performance, resulting in negative behavioral, physiological, or emotional responses in evaluation situations (von der Embse et al., 2018; Zeidner, 1998). High test-anxious (HTA) individuals showed attention bias (ABs) (Jastrowski Mano et al., 2018; Zhang et al., 2018) and inhibition deficits for test-related stimuli (Wei et al., 2021; Zhang et al., 2019). Specifically, the deficits model of test anxiety suggested that ABs and inhibition deficits are causal ingredients and underlying mechanisms of anxiety-related performance deficits, which in turn maintain test anxiety (Zeidner, 1998; Zeidner et al., 2005).

Most studies examined ABs and inhibition deficits in test anxiety individually. Some research found that HTA individuals showed ABs to test-related stimuli in a dot-probe task (Jastrowski Mano et al., 2018; Zhang et al., 2018). The other research observed inhibition impairments in an emotional Stroop task and Flanker task (Wei et al., 2021; Wei et al., 2021; Zhang et al., 2019). Mogg et al. (2016) indicated that anxiety is involved a complex interaction among several cognitive processes, including attention selection and inhibitory control. Thus, treating ABs and inhibition deficit as a unitary construct and characterizing its specific role is crucial for understanding pathology and maintenance of test anxiety.

However, ABs and inhibition deficits in test anxiety may be specified with test-related stimuli or evaluative situations in previous research (e.g., Jastrowski Mano et al., 2018; Zhang et al., 2019; Zhang et al., 2018).

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Pourtois et al. (2013) suggested that threatening information may enhance processing efficiency by mediating distinct neural mechanisms in amygdala and interconnected prefrontal areas. Thus, the disturbances of attentional processes in test anxiety may result from specific effects caused by test-related threats. To examine how test anxiety synchronously affects attention selection and inhibitory function without threatening information is urgent.

Moreover, previous findings of ABs and inhibition deficits in test anxiety rely on specific experimental conditions in dot-probe and Stroop tasks, which always presented with simple visual displays (e.g., Jastrowski Mano et al., 2018; Zhang et al., 2019). Selective attention is a limited-capacity cognitive system that selects high-priority signals for further processing from various stimuli (Dolan et al., 2010). A selective attentional mechanism is limited if it only operates in simple visual environments (Richards et al., 2014; Weierich et al., 2008). Thus, exploring how test anxiety affects attention in complex visual environments is indispensable.

The additional singleton task (AST) is ideal for investigating attention selection and inhibitory processes in a unitary construct (Moran et al., 2015; Moser et al., 2012). Participants searched for a target and ignored a more salient singleton distractor in circular displays (Theeuwes, 2010). Previous research suggests that singleton distractors will capture attention automatically when suppression fails and could be suppressed by some top-down mechanism (Gaspelin et al., 2018; 2019; Luck et al., 2021). Accordingly, the AST can synchronously measure attention capture and inhibition of irrelevant singletons.

Moreover, search strategies can affect attention capture of singleton distractors in the AST (Barras et al., 2016; Theeuwes, 2010). Bacon et al. (1994) proposed singleton detection and feature search modes in the visual search task. The former mode relies on local salience and preferentially allocates attention to the most salient information (e.g., singleton). In contrast, the latter mode capitalizes on observers' abilities to impose top-down selectivity and should not be susceptible to capturing attention by singleton distractors (Leber et al., 2006). When observers 'choose' a feature search mode, attention capture of irrelevant singletons can be reduced (Barras et al., 2016). To minimize interferences of singleton distractors and give participants access to a feature search mode, the target shape in our experiments was fixed as a diamond (Barras et al., 2016).

Besides, combining AST with identified event-related potentials (ERPs) components can precisely examine attentional selection and suppression of singleton distractors (Gaspar et al., 2018). The posterior contralateral N2 (N2pc) reflected covert attention selection of stimuli, which occurs 200–300 ms after the onset of a search display (Hickey et al., 2006). The N2pc was more remarkable for the attended than the unattended stimuli (Kappenman et al., 2014). The distractor positivity, or PD, is an enhanced positivity elicits over posterior brain areas contralateral to distractors between 200 and 400 ms after the onset of the search display and reflects active distractor suppression (e.g., Sawaki et al., 2012). Song et al. (2021) found that HTA individuals displayed filtering deficits in a change detection task. To explore whether the filtering deficits will extend in a visual search task, we also track the sustained posterior contralateral negativity (SPCN). This lateralized component often follows the N2pc and is usually elicited between 300 and 650 ms after stimulus onset and reflects the neural activity of information maintenance in working memory (e.g., Jolicoeur et al., 2008).

Here, we combined ERPs techniques and AST to track attention capture and inhibitory process of irrelevant singletons in test anxiety. Previous research suggested a broader attention dysregulation in anxiety (e.g., Bishop, 2009; Moran et al., 2015). Accordingly, we predicted that HTA individuals would show ABs toward irrelevant singletons reflected by a reliable distractor N2pc. Moreover, the HTA group would fail to filter singleton distractors by showing a minor distractor PD and a distractor SPCN. Previous research proposed that attention capture of singleton distractors could be inhibited by goal-directed mechanisms (Gaspelin et al., 2018, 2019; Luck et al., 2021). Thus, we predicted that the low test-anxious (LTA) group would inhibit singleton distractors by showing larger distractor PD.

2. Method

2.1. Participants

Initially, 386 students were recruited via online advertisements posted in the online recruitment forums of the university and screened by completing the Chinese version of the test anxiety scale (TAS-C)[1](Wang, 2001). TAS-C scores of 20 or above were considered for HTA (89) and 12 or lower for LTA (76) (Newman, 1996). However, some participants[2] refused to attend experiments after they knew the procedures of the experiments. Finally, 56 participants (*M age* = 21.2, *SD* = 2.6) attended the experiments with 28 participants in each group. The HTA group (8 males) had M TAS-C scores = 25.29; SD TAS-C scores = 3.86, and LTA group (13 males) had M TAS-C scores = 8.79, SD TAS-C scores = 2.87. TAS-C scores of the HTA group were significantly higher than the LTA group, $t(50) = 18.16$, $p < 0.01$.

All participants gave informed consent and were paid ¥ 40 for their time. All were naïve to the purpose of the study and reported normal or corrected-to-normal visual acuity and declared themselves free of neurological disorders. All procedures were approved by the local ethics committee in accordance with the Declaration of Helsinki.

2.2. Stimulus, apparatus and procedure

Nine unfilled circles and a diamond (size: 4.2° × 4.2°) consisted of search arrays and presented equidistantly (9.2°) from central fixation. Each circle was 3.4° in diameter with a 0.3°-thick outline. Eight or 9 of the circles were color distractors, one diamond was a target, and one circle was a singleton distractor with a different color from other stimuli. A grey line (0.3° × 1.5°) randomly oriented either vertically or horizontally was contained within each stimulus. The outlines of stimuli thinned 0.3° were either red (RGB:255,0,0) or green (RGB:0,255,0). In 25% of total trials, the target was a unique stimulus and randomly presented to one of eight lateralized screen positions. In the remaining trials, one circled stimulus had a different color from other stimuli,

Table 1
The statistics of the TAS-C scores of individuals who did and did not participate.

		N	Mean	t	p
All	participate	56	17.04	−0.701	0.484
	did not participate	109	18.07		
HTA	participate	28	25.29	−0.009	0.993
	did not participate	61	25.30		
LTA	participate	28	8.79	−0.186	0.853
	did not participate	48	8.90		

Abbreviations: HTA represents high test anxiety; LTA represents low test anxiety.

[1] TAS-C was revised from the test anxiety scale (TAS) by Sarason (1978). There are 37 items of TAS-C, which are scored using the two true/false answer categories. The total score of TAS-C ranges from 0 to 37, while a higher score indicates higher test anxiety. The reliability and validity of TAS-C have been established in previous research (Wang, 2001), and the internal reliability coefficients for the present study were 0.819.

[2] Sixty-one participants of the HTA group and forty-eight participants of the LTA group did not participate after knowing the procedures of the experiments (they refused to attend experiments for time conflicts and unwillingness to wear the equipment or wash their hair with shampoo in the lab). The TAS-C scores showed no differences between individuals who did and did not decide to participate ($ts \leq -701$, $ps \geq 0.484$, see details in Table 1).

either red among green stimuli or green among red stimuli. Target and singleton distractor locations were varied to produce the following display configurations: lateral target/no distractor (T_LD_A, 25.0%); lateral target/midline distractor (T_LD_M,17%); lateral target/ipsilateral distractor (T_LD_I,17%); lateral target/contralateral distractor (T_LD_C,17%); midline target/lateral distractor (T_MD_L,17%); and midline target/midline distractor (T_MD_M,11%). The experiment contained 22 blocks, 1122 trials per participant. Twenty practice trials were given before the formal experiment.

All stimuli were presented on a black background on an LCD monitor (resolution: 1024 × 768; frame rate: 60 Hz) about 57 cm away from the viewers. Each trial began with a fixation for a random duration of 1000–1500 ms (see Fig. 1), followed by a visual search array presented at 200 ms. Participants were instructed to respond in 2000 ms based on the orientation of the line contained in the target. The target held a vertical line in half of the trials and a horizontal line in the remainder. Participants had to maintain eye fixation throughout the experiment and were told that eye movements were being monitored.

2.3. Electrophysiology

The electrophysiological (EEG) data were collected using a Neuro-Scan recording system and a 64-electrode head cap designed according to the International 10/20 system at a 1000 Hz sampling rate. The impedances were kept below 10 kΩ. The electrode placed on the left mastoid was a reference during recording and was re-referenced offline to the average left/right mastoid. The horizontal and vertical EOG signals were measured from electrodes 1 cm lateral to the outer canthi of each eye and an electrode placed below the right eye.

EEG data analyses were performed in MATLAB using EEGLAB Toolbox (Delorme et al., 2004) and ERPLAB Toolbox (Lopez-Calderon et al., 2014) and resampled offline to 500 HZ. Continuous EEG data were filtered with a 30 Hz low-pass filter and a 0.1 Hz high-pass filter. Averaged ERP waveforms were computed with an 800 ms epoch starting 200 ms before and ending 600 ms after the onset of visual search arrays, and baselines were computed using 200 ms pre-stimuli. Single epochs were removed if the peak-to-peak voltage was over 200 μV in any 200 ms window in any electrodes or if a blink or eye movement was detected in uncorrected HEOG signals between 100 and 600 ms after visual search displays or in VEOG signals between 200 ms before and 600 ms after visual search displays. Independent component analysis (ICA) was used for all electrodes except mastoid electrodes and HEOG and VEOG channels to correct eye blinks and horizontal eye movements.

Six participants (3 participants of the HTA group and 3 participants of the LTA group) were excluded as more than 30% of trials were rejected. The average percentage of rejected trials was 11.21% (range 0.8–30%).

The N2pc and PD were defined as contralateral-minus-ipsilateral difference waves at electrodes P7/P8, in which difference waves in these scalp sites were usually maximal (e.g., Wei et al., 2021). The distractor N2pc was computed in a 60-ms window from 230 ms to 290 ms (Hickey et al., 2006). For lateral target N2pc, to test whether lateral distractors initially elicit N2pc in the lateral target displays, Hickey et al. (2006) suggested an early distractor N2pc (220–265 ms) and a later target N2pc (275–350 ms). Accordingly, we would compute these two windows for lateral targets. The distractor PD was computed in a time window from 300 ms to 400 ms (e.g., McDonald et al., 2013; Sawaki et al., 2012). The distractor and target SPCN were computed in a 150 ms window from 350 ms to 500 ms (Salahub et al., 2018).

3. Results

3.1. Behavioural data

Response times (RTs) of error trials (12.20%) or excessively fast or slow responses (RTs <300 ms or RTs >2,000 ms; 1.06%) were removed from the analysis. A 2 (condition: distractor-present, distractor-absent) × 2 (group: HTA, LTA) repeated-measures ANOVA of accuracies found significant effects on the condition, $F(1, 48) = 6.67$, $p = 0.013$, $\eta_p^2 = 0.122$. Accuracies for the distractor-absent condition ($M = 90.06\%$, $SE = 0.007$) was significantly higher than for the distractor-present condition ($M = 89.05\%$, $SE = 0.007$). The main effects of the group were marginally significant, $F(1, 48) = 3.97$, $p = 0.052$, $\eta_p^2 = 0.076$. Accuracies of the HTA group ($M = 90.9\%$, $SE = 0.01$) was higher than the LTA group ($M = 88.21\%$, $SE = 0.01$). The interaction between group and condition was not significant, $F(1, 48) = 0.14$, $p = 0.706$, $\eta_p^2 = 0.003$.

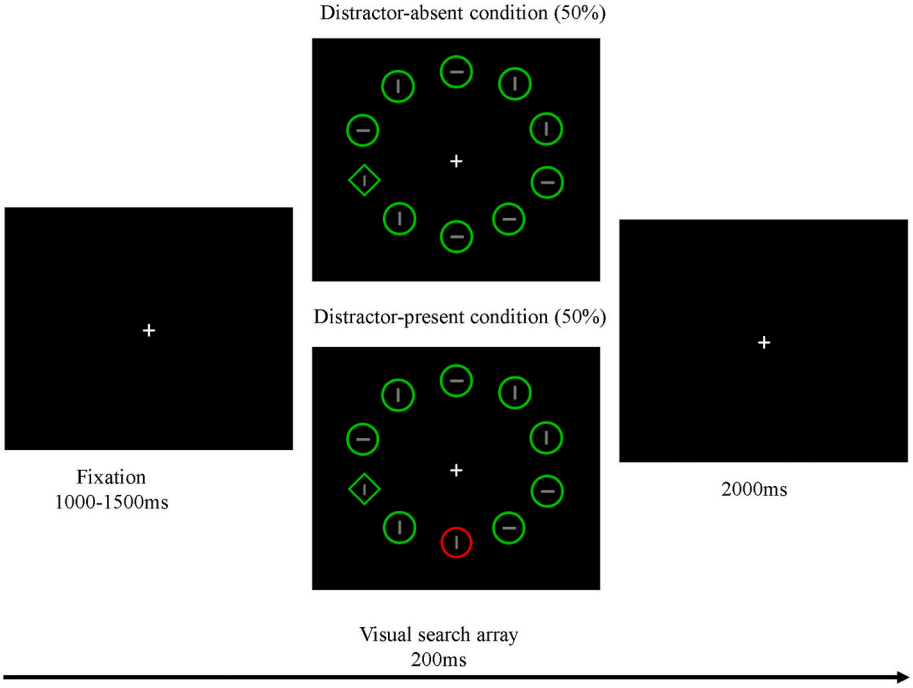

Fig. 1. Example of the flow of events on a trial.

A 2 × 2 repeated-measures ANOVA of RTs found significant effects on the condition, $F(1, 48) = 26.89$, $p < 0.001$, $\eta_p^2 = 0.359$. RTs for the distractor-absent condition ($M = 780$ ms, $SE = 11.74$) was faster than for the distractor-present condition ($M = 795$ ms, $SE = 12.1$). No main effects of group were observed, $F(1, 48) = 0.28$, $p = 0.599$, $\eta_p^2 = 0.006$. The group × condition interaction was significant, $F(1, 48) = 4.7$, $p = 0.035$, $\eta_p^2 = 0.089$. For both groups, faster responses were found for the distractor-absent condition (HTA: $M = 783$ ms, $SE = 16.43$, $p < 0.001$; LTA: $M = 777$ ms, $SE = 16.77$, $p = 0.038$) than for the distractor-present condition (HTA: $M = 804$ ms, $SE = 17.98$; LTA: $M = 787$ ms, $SE = 16.18$). No differences were found for RTs between groups ($ps \geq 0.44$).

To indicate the magnitude of behavioral interferences of each group, we analyzed RTs differences between distractor-present and distractor-absent trials. An independent-sample *t*-test showed that RTs differences for the HTA group ($M = 20.75$ ms, $SE = 3.69$) was larger than the LTA group ($M = 8.52$ ms, $SE = 4.27$), $t(48) = 2.17$, $p = 0.04$, 95% CI = [0.88, 23.58].

3.2. ERP data

3.2.1. Singleton distractor N2pc, PD, and SPCN

Fig. 2 shows grand-averaged ERPs for the T_MD_L display. Table 2 shows statistical tests for lateralized ERPs of singleton distractors. The HTA showed a significant distractor N2pc ($p = 0.048$) and SPCN ($p = 0.033$). The LTA group had a significant distractor PD ($p = 0.002$) and a more positive deflection at electrodes contralateral than at ipsilateral to distractors in the interval of SPCN.

An independent-sample *t*-test showed that distractor N2pc for the HTA group ($M = -0.245$ μV, $SE = 0.117$) showed a larger trend than the LTA group ($M = 0.016$ μV, $SE = 0.096$), $t(48) = 1.715$, $p = 0.093$, 95% CI = [−0.567, 0.045], but distractor PD for the LTA group ($M = 0.346$ μV, $SE = 0.097$) was significantly larger than for the HTA group ($M = -0.056$ μV, $SE = 0.109$), $t(48) = -2.76{,}4$ $p = 0.008$, 95% CI = [−0.69, −0.11]. The distractor SPCN for the HTA group ($M = -0.296$ μV, $SE = 0.132$) was significantly negative than for the LTA group ($M = -0.203$ μV, $SE = 0.09$), $t(48) = -3.11$, $p = 0.003$, 95% CI = [−0.82, −0.17].

3.2.2. Target N2pc and SPCN

To test whether lateral distractors initially elicit N2pc in lateral target displays, we analyzed the early distractor N2pc (220–265 ms) and later target N2pc (275–350 ms) for the displays with the lateral target. The HTA group showed no significant early distractor N2pc in the T_LD_C display (ps = 0.198) and had a significant early distractor N2pc in the other condition, $ts \geq -2.82$, $ps \leq 0.01$. The LTA group showed a significant early distractor N2pc in all lateral target conditions, $ts \geq -2.033$, $ps \leq 0.028$. Both groups found a significant later target N2pc (see Table 3), $ts \geq -4.57$, $ps \leq 0.001$.

Hickey et al. (2006) suggested that target N2pc would be larger for the T_LD_I display than for the T_LD_C display as the attention capture of singleton distractors facilitated attention engagement of targets. To test this possibility, we analyzed early distractor N2pc and later target N2pc between T_LD_I, T_LD_C and T_LD_A displays. A 3 (condition: T_LD_A, T_LD_C, T_LD_I) × 2 (group: HTA, LTA) repeated-measures ANOVA showed a significant condition × group interaction of early distractor N2pc, $F(2, 96) = 6.435$, $p = 0.002$, $\eta_p^2 = 0.118$. The early distractor N2pc for the T_LD_I display ($M = -0.72$ μV, $SE = 0.14$) was larger than the T_LD_A ($M = -0.39$ μV, $SE = 0.14$, $p = 0.029$) and T_LD_C ($M = -0.21$ μV, $SE = 0.15$, $p = 0.005$) display in the HTA group (see Fig. 3A). For the LTA group (see Fig. 3B), no differences were observed between these conditions ($ps \geq 0.803$). The early distractor N2pc of the HTA group for the T_LD_I display ($M = -0.72$ μV, $SE = 0.14$, $p = 0.034$) was larger than the LTA group ($M = -0.31$ μV, $SE = 0.14$, see Fig. 3C). No other significant differences between groups were found for the T_LD_C display ($p = 0.107$, see Fig. 3D). No main effects were observed on condition ($F(2, 96) = 0.807$, $p = 0.449$, $\eta_p^2 = 0.017$) and group ($F(1, 48) = 0.002$, $p = 0.967$, $\eta_p^2 = 0$).

A 3 × 2 repeated-measures ANOVA showed no significant effects of target N2pc, $Fs(2, 96) \leq 1.29$, $ps \geq 0.281$, $\eta_p^2 \leq 0.118$.

Both groups showed a target SPCN ($ts \geq -3.519$, $ps \leq 0.002$). To test whether the HTA group would inhibit singleton distractors in lateral target displays, we also analyzed target SPCN. A 3 × 2 repeated-measures ANOVA of target SPCN showed significant main effects of the condition, $F(2, 96) = 5.125$, $p = 0.008$, $\eta_p^2 = 0.096$. Moreover, the condition × group interaction was marginally significant, $F(2, 96) = 2.994$, $p = 0.055$, $\eta_p^2 = 0.059$. For the HTA group (see Fig. 3A), target SPCN for the T_LD_I display ($M = -1.548$ μV, $SE = 0.212$) was larger than the T_LD_A ($M = -1.144$ μV, $SE = 0.264$, $p = 0.031$) and T_LD_C ($M = -0.921$ μV, $SE = 0.252$, $p = 0.001$) display. No differences were found for target SPCN between the T_LD_A and T_LD_C ($p = 0.512$) display. For the LTA group (see Fig. 3B), no differences were observed between these conditions ($ps \geq 1$). The main effects on the group were not significant, $F(2, 96) = 0.191$, $p = 0.664$, $\eta_p^2 = 0.004$.

4. Discussion

The present study aimed to synchronously investigate attention capture and inhibition of irrelevant singletons in test anxiety. Consequently, the HTA and LTA groups showed faster responses and higher accuracies in the distractor-absent condition than in the distractor-present condition. However, RTs differences between distractor-present and distractor-absent conditions of the HTA group were larger than the LTA group. Accuracies of the HTA group showed a better trend

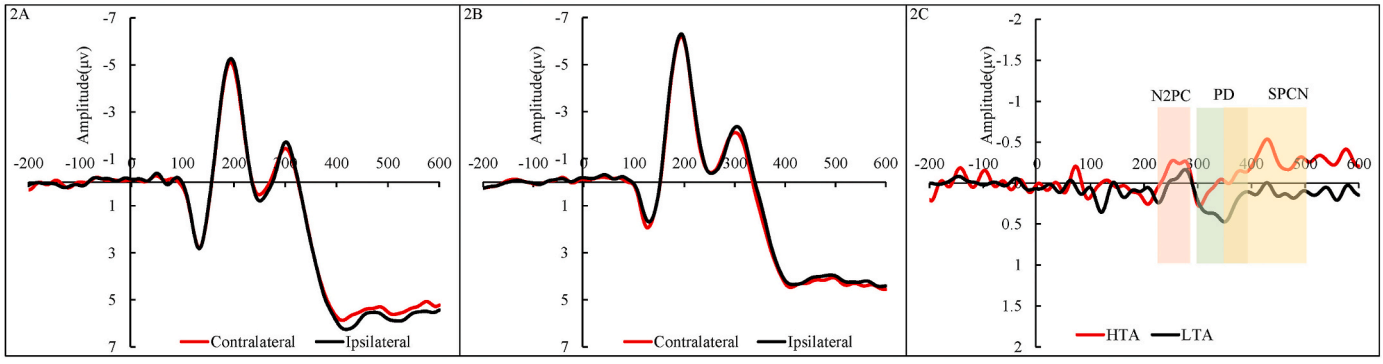

Fig. 2. Shows the event-related potentials elicited by search displays containing a midline target and a lateral distractor. Fig. 2A shows the grand-averaged event-related potential waveforms recorded contralaterally and ipsilaterally to singleton distractors for the HTA group. Fig. 2B shows the grand-averaged event-related potential waveforms recorded contralaterally and ipsilaterally to singleton distractors of the LTA group. Fig. 2C shows contralateral-minus-ipsilateral (Contra-Ipsi) difference waveforms for the HTA group and the LTA group and examples of search displays containing a midline target and a lateral distractor.
Abbreviations: HTA represents high test anxiety; LTA represents low test anxiety.

Table 2
The contralateral waves minus ipsilateral waves of lateral distractors in midline target/lateral-distractor displays.

		Distractor N2pc			Distractor PD			Distractor SPCN		
Group	Condition	Mean	T	p	Mean	t	p	Mean	t	p
HTA	Midline target/lateral-distractor	−.245	−2.08	.048*	−.056	−.513	.613	−.296	−2.227	.036*
LTA	Midline target/lateral-distractor	.016	−.167	.869	.347	3.572	.002*	.204	2.261	.033*

Note: The mean column presents mean difference waves computed by contralateral waves minus ipsilateral waves in midline target/lateral-distractor displays. The t presents paired sample *t*-test comparing differences between contralateral and ipsilateral waves of lateral distractors. * Denotes statistically significant at the p = 0.05 level.
Abbreviations: HTA represents high test anxiety; LTA represents low test anxiety.

Table 3
The contralateral waves minus ipsilateral waves of lateral targets.

		Early distractor N2pc			Later target N2pc			Target SPCN		
Group	Condition	Mean	t	p	Mean	t	p	Mean	t	p
HTA	Lateral target/midline distractor	−0.536	−2.819	.010*	−1.2979	−5.78	.000*	−1.301	−4.871	0.000*
	Lateral target/no distractor	−0.38816	−3.175	.004*	−1.1152	−6.469	.000*	−1.144	−4.955	0.000*
	Lateral target/ipsilateral distractor	−0.72428	−5.301	.000*	−1.2514	−8.309	.000*	−1.548	−9.007	0.000*
	Lateral target/contralateral distractor	−0.2068	−1.325	0.198	−0.9349	−4.96	.000*	−0.921	−3.730	0.001*
LTA	Lateral target/midline distractor	−0.39312	−2.332	.028*	−1.0598	−4.566	.000*	−1.026	−4.713	0.000*
	Lateral target/no distractor	−0.47948	−2.947	.007*	−1.1565	−5.016	.000*	−1.033	−3.519	0.002*
	Lateral target/ipsilateral distractor	−0.3076	−2.303	.030*	−1.1024	−4.924	.000*	−1.120	−4.546	0.000*
	Lateral target/contralateral distractor	−0.5522	−3.924	.001*	−1.1708	−5.901	.000*	−1.042	−4.063	0.000*

Note: The mean column presents mean difference waves computed by contralateral waves minus ipsilateral waves of lateral targets. The t presents paired sample *t*-test comparing the differences between contralateral and ipsilateral waves of targets. * Denotes statistically significant at the p = 0.05 level.
Abbreviations: HTA represents high test anxiety; LTA represents low test anxiety.

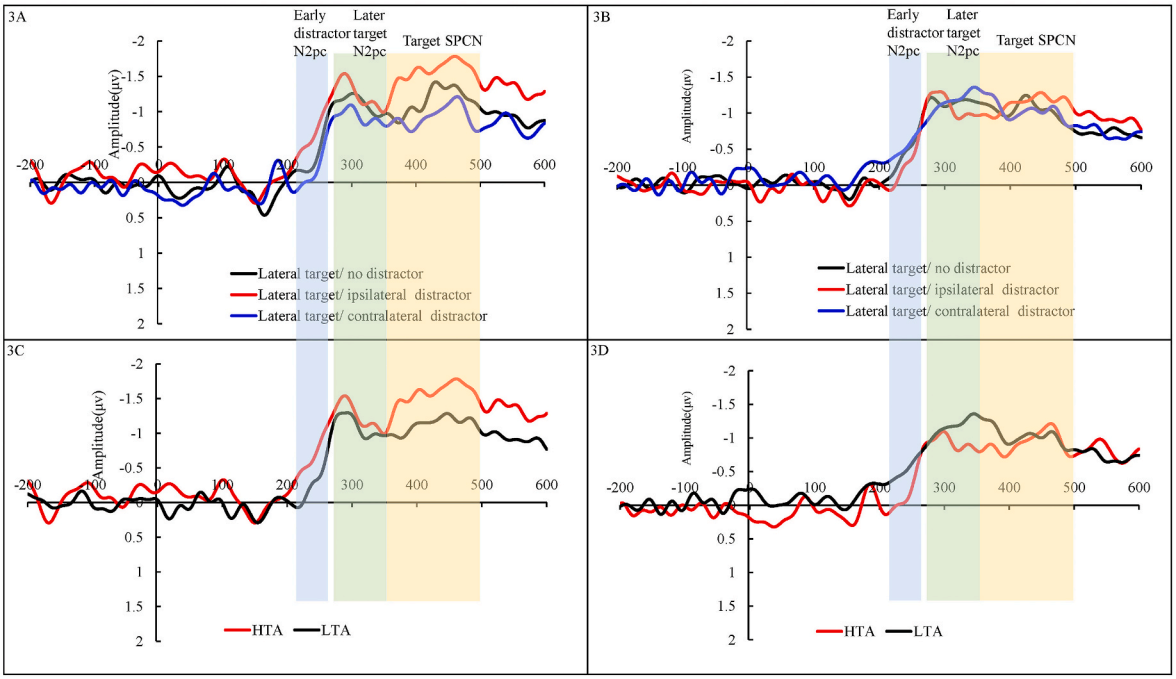

Fig. 3. Shows the contralateral-minus-ipsilateral difference waveforms by search displays containing a lateral target. Fig. 3A shows the contralateral-minus-ipsilateral difference waveforms in the lateral target/no distractor displays, lateral target/ipsilateral distractor displays and lateral target/contralateral distractor displays for the HTA group. Fig. 3B shows the contralateral-minus-ipsilateral difference waveforms in the lateral target/no distractor displays, lateral target/ipsilateral distractor displaysand lateral target/contralateral distractor displays for the LTA group. Fig. 3C shows the contralateral-minus-ipsilateral difference waveforms in the lateral target/ipsilateral distractor displays for the HTA and LTA groups. Fig. 3D shows the contralateral-minus-ipsilateral difference waveforms in the lateral target/contralateral distractor displays for both the HTA and LTA groups.
Abbreviations: HTA represents high test anxiety; LTA represents low test anxiety.

than the LTA group. Consistent with our hypothesis, the HTA group had a distractor N2pc and SPCN for the T_MD_L display. The LTA group had a larger distractor PD than the HTA group. Besides, the HTA group showed larger N2pc and SPCN for the T_LD_I display.

We found that the HTA and LTA groups were interfered with singleton distractors by showing longer RTs and lower accuracies in the distractor-present condition. The larger RTs differences between distractor-present and distractor-absent conditions and a distractor

N2pc indicated that the HTA group attained more behavioral interferences and enhanced ABs from singleton distractors. Previous research reported that distractor N2pc is shown in the condition with unpredictable targets, in which observers have to use singleton detection mode (Barras et al., 2016; Burra et al., 2013). Additionally, behavioral interferences were larger in the singleton search mode compared to the feature search mode (Barras et al., 2016). Here, the target shape was fixed as a diamond, in which participants could access a feature search mode (Barras et al., 2016). Thus, the HTA group had ABs to singleton distractors even though they could access a feature search mode. Besides, the HTA group showed larger early distractor N2pc for the T_LD_I display, suggesting that the HTA group used a singleton detection mode (Hickey et al., 2006). Moreover, attention capture of irrelevant singletons reflects a stimulus-driven effect driven by salience alone (Wang et al., 2016). Anxiety is associated with enhanced stimulus-driven attention, leading to automatic orienting to salient stimuli (Corbetta and Shulman, 2002; Mogg et al., 2016). Accordingly, we concluded that test anxiety enhanced the effects on stimulus-driven attention systems.

Besides, the HTA group had no significant distractor PD but a distractor SPCN. A distractor PD was associated with the active suppression of singleton distractors (Gaspar et al., 2016). A distractor N2pc followed by a distractor SPCN indicated that the HTA group failed to suppress singleton distractors and remained in the visual working memory (Eimer et al., 2010). Moreover, the HTA group presented a larger early distractor N2pc and a larger target SPCN for T_LD_I display than the T_LD_A and T_LD_C. Gaspar et al. (2014) demonstrated that the N2pc was largest with the contralateral distractor and smallest with the ipsilateral distractor as attention capture of singleton distractors was inhibited. Consequently, the HTA group failed to deter singleton distractors from the working memory, increasing the target N2pc and SPCN. Behaviourally, the HTA group had larger behavioural interferences and better performances than the LTA group. Previous research implies that goal-directed mechanisms could suppress ABs of singleton distractors (e.g., Gaspelin et al., 2018, 2019). Hence, suppression failures could be explained as test anxiety weakened the function of goal-directed attention systems.

For the LTA group, we found a distractor PD for the T_MD_L display in the time range from 300 ms to 400 ms, suggesting that the LTA group could proactively prevent singleton distractors from in-depth processing (Gaspar et al., 2014). However, previous research found that the PD of proactive suppression usually presented at a similar time window to the N2pc (e.g., Gaspar et al., 2014; Gaspelin et al., 2018). The distractor PD in the LTA group appeared after a distractor N2pc. Thus, the distractor PD could be overlapped with the distractor N2pc, resulting in no significant distractor N2pc in the LTA group. The accounts of rapid disengagements (Theeuwes, 2010) claimed that the top-down suppression that occurred following the initial orientation to singleton distractors were more likely to explain the results of the LTA group. In addition, the LTA group had weaker behavioral interferences than the HTA group. Barras et al. (2016) found that individuals get smaller behavioral interferences from singleton distractors and have no differences in the target N2pc between T_LD_I and T_LD_M displays when using feature search modes. Also, the LTA group showed no differences between all lateral target conditions of early distractor N2pc and late target N2pc, proposing that the LTA group used a feature search mode.

By combining AST and ERPs components, we provided temporally and dual-process distinctions related attention selection and inhibitory processes in test anxiety and attained direct evidence that test anxiety increased the effects of stimulus-driven attention systems and weakened the function of goal-directed attention systems. Our electrophysiological findings for HTA and LTA groups might imply different mechanisms or brain activities and help us to understand how test-anxious individuals deal with distractions and cognitive consequences. Additionally, previous research suggested that test anxiety is a situation-specific anxiety disorder, in which ABs and inhibition deficits in test anxiety are specified in test-related threats or within evaluative situations (Jastrowski Mano et al., 2018; Wei et al., 2021). However, our data indicated that HTA individuals had ABs and inhibition deficits of general salient distractors, suggesting that test-anxious individuals involved broader attention dysregulation that extends beyond particular stimuli or situations. Enriching the deficits model of test anxiety, present results implied that general attention deficits might be contributed to test anxiety. Thus, strengthening general inhibitory control, such as training individuals to ignore neutral task-irrelevant information and suppressing general stimuli, may be used to intervene in test anxiety.

Our research has some limitations. Firstly, participants of the current research were selected from college students according to their self-reported TAS-C scores. Thus, the generalization of present findings was limited. Additional research is needed to examine whether obtained results can be generalized to clinical populations. Secondly, the small sample size and extreme group method of the present study may result in lower statistical power and reproducibility(Simonsohn, 2015). Future research can make a design with a larger sample size and explore ABs and inhibition deficits across all levels of test anxiety.

5. Conclusions

We found that high test-anxious individuals showed ABs to singleton distractors and failed to suppression, and indicated that test anxiety could increase the effects of stimulus-driven attention systems and weaken the function of goal-directed attention systems.

Contributors

CH and RZ designed the experiment. CH, JS, and YH collected and analyzed the data. CH and RZ contributed to data interpretation. CH and RZ wrote the paper. All authors contributed to manuscript revision, read and approved the submitted version.

Role of the funding source

The funders had no role in the study design, conduct of the study; in 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

No conflict of interests.

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References

Bacon, W.F., et al., 1994. Overriding stimulus-driven attentional capture. Percept. Psychophys. 55 (5), 485–496.
Barras, C., et al., 2016. Active suppression of salient-but-irrelevant stimuli does not underlie resistance to visual interference. Biol. Psychol. 121 (Pt A), 74–83. https://doi.org/10.1016/j.biopsycho.2016.10.004.
Bishop, S.J., 2009. Trait anxiety and impoverished prefrontal control of attention. Nat. Neurosci. 12 (1), 92–98. https://doi.org/10.1038/nn.2242.
Burra, N., et al., 2013. Attentional capture during visual search is attenuated by target predictability: evidence from the N2pc, Pd, and topographic segmentation. Psychophysiology 50 (5), 422–430. https://doi.org/10.1111/psyp.12019.
Corbetta, M., et al., 2002. Control of goal-directed and stimulus-driven attention in the brain. Nat. Rev. Neurosci. 3 (3), 201.
Delorme, A., et al., 2004. EEGLAB: an open source toolbox for analysis of single-trial EEG dynamics including independent component analysis. J. Neurosci. Methods 134 (1), 9–21. https://doi.org/10.1016/j.jneumeth.2003.10.009.
Dolan, R.J., et al., 2010. Amygdala automaticity in emotional processing. Ann N Y Acad 985 (1), 348–355.

Eimer, M., et al., 2010. Top-down search strategies determine attentional capture in visual search: behavioral and electrophysiological evidence. Atten. Percept. Psychophys. 72 (4), 951–962. https://doi.org/10.3758/APP.72.4.951.
Gaspar, J.M., et al., 2016. Inability to suppress salient distractors predicts low visual working memory capacity. Proc. Natl. Acad. Sci. U. S. A. 113 (13), 3693–3698. https://doi.org/10.1073/pnas.1523471113.
Gaspar, J.M., et al., 2014. Suppression of salient objects prevents distraction in visual search. J. Neurosci. 34 (16), 5658–5666. https://doi.org/10.1523/JNEUROSCI.4161-13.2014.
Gaspar, J.M., et al., 2018. High level of trait anxiety leads to salience-driven distraction and compensation. Psychol. Sci. https://doi.org/10.1177/0956797618807166, 956797618807166.
Gaspelin, N., et al., 2018. Combined electrophysiological and behavioral evidence for the suppression of salient distractors. J. Cognit. Neurosci. 30 (9), 1265–1280. https://doi.org/10.1162/jocn_a_01279.
Gaspelin, N., et al., 2019. Inhibition as a potential resolution to the attentional capture debate. Curr Opin Psychol 29, 12–18. https://doi.org/10.1016/j.copsyc.2018.10.013.
Hickey, C., et al., 2006. Electrophysiological evidence of the capture of visual attention. J. Cognit. Neurosci. 18 (4), 604–613. https://doi.org/10.1162/jocn.2006.18.4.604.
Jastrowski Mano, K.E., et al., 2018. Attentional bias toward school-related academic and social threat among test-anxious undergraduate students. Learn. Indiv Differ 64, 138–146. https://doi.org/10.1016/j.lindif.2018.05.003.
Jolicoeur, P., et al., 2008. Dissociation of the N2pc and sustained posterior contralateral negativity in a choice response task. Brain Res. 1215, 160–172. https://doi.org/10.1016/j.brainres.2008.03.059.
Kappenman, E.S., et al., 2014. Behavioral and ERP measures of attentional bias to threat in the dot-probe task: poor reliability and lack of correlation with anxiety. Front. Psychol. 5, 1368. https://doi.org/10.3389/fpsyg.2014.01368.
Leber, A.B., et al., 2006. It's under control: top-down search strategies can override attentional capture. Psychon. Bull. Rev. 13 (1), 132–138. https://doi.org/10.3758/BF03193824.
Lopez-Calderon, J., et al., 2014. ERPLAB: an open-source toolbox for the analysis of event-related potentials. Front. Hum. Neurosci. 8 (213) https://doi.org/10.3389/fnhum.2014.00213.
Luck, S.J., et al., 2021. Progress toward resolving the attentional capture debate. Vis cogn 29 (1), 1–21. https://doi.org/10.1080/13506285.2020.1848949.
McDonald, J.J., et al., 2013. On the electrophysiological evidence for the capture of visual attention. J. Exp. Psychol. Hum. Percept. Perform. 39 (3), 849–860. https://doi.org/10.1037/a0030510.
Mogg, K., et al., 2016. Anxiety and attention to threat: cognitive mechanisms and treatment with attention bias modification. Behav. Res. Ther. 87, 76–108. https://doi.org/10.1016/j.brat.2016.08.001.
Moran, T.P., et al., 2015. The color of anxiety: neurobehavioral evidence for distraction by perceptually salient stimuli in anxiety. Cognit. Affect Behav. Neurosci. 15 (1), 169–179. https://doi.org/10.3758/s13415-014-0314-7.
Moser, J.S., et al., 2012. Enhanced attentional capture in trait anxiety. Emotion 12 (2), 213–216. https://doi.org/10.1037/a0026156.
Newman, E., 1996. No more test anxiety: effective steps for taking tests and achieving better grades. Learning Skillspubns 1.
Pourtois, G., et al., 2013. Brain mechanisms for emotional influences on perception and attention: what is magic and what is not. Biol. Psychol. 92 (3), 492–512. https://doi.org/10.1016/j.biopsycho.2012.02.007.
Richards, H.J., et al., 2014. Exploring the function of selective attention and hypervigilance for threat in anxiety. Clin. Psychol. Rev. 34 (1), 1–13. https://doi.org/10.1016/j.cpr.2013.10.006.
Salahub, C.M., et al., 2018. ERP evidence for temporal independence of set size and object updating in object substitution masking. Atten. Percept. Psychophys. 80 (2), 387–401. https://doi.org/10.3758/s13414-017-1459-6.
Sawaki, R., et al., 2012. A common neural mechanism for preventing and terminating the allocation of attention. J. Neurosci. 32 (31), 10725–10736. https://doi.org/10.1523/JNEUROSCI.1864-12.2012.
Simonsohn, U., 2015. Small telescopes: detectability and the evaluation of replication results. Psychol. Sci. 26 (5), 559–569. https://doi.org/10.1177/0956797614567341.
Song, J., et al., 2021. Test anxiety impairs filtering ability in visual working memory: evidence from event-related potentials. J. Affect. Disord. 292, 700–707. https://doi.org/10.1016/j.jad.2021.05.091.
Theeuwes, J., 2010. Top-down and bottom-up control of visual selection. Acta Psychol. 135 (2), 77–99. https://doi.org/10.1016/j.actpsy.2010.02.006.
von der Embse, N., et al., 2018. Test anxiety effects, predictors, and correlates: a 30-year meta-analytic review. J. Affect. Disord. 227, 483–493. https://doi.org/10.1016/j.jad.2017.11.048.
Wang, C.K., 2001. Reliability and validity of test-anxiety scale of Chinese version. Chin. Ment. Health J. 15 (2), 96–97.
Wang, E., et al., 2016. Attentional selection and suppression in children with attention-deficit/hyperactivity disorder. Biol Psychiatry Cogn Neurosci Neuroimaging 1 (4), 372–380. https://doi.org/10.1016/j.bpsc.2016.01.004.
Wei, H., et al., 2021a. Enhanced or impoverished recruitment of top-down attentional control of inhibition in test anxiety. Biol. Psychol. 161, 108070 https://doi.org/10.1016/j.biopsycho.2021.108070.
Wei, H., et al., 2021b. Test anxiety impairs inhibitory control processes in a performance evaluation threat situation: evidence from ERP. Biol. Psychol., 108241 https://doi.org/10.1016/j.biopsycho.2021.108241.
Wei, P., et al., 2021. Reward expectation modulates N2pc for target selection: electrophysiological evidence. Psychophysiology 58 (8), e13837. https://doi.org/10.1111/psyp.13837.
Weierich, M.R., et al., 2008. Theories and measurement of visual attentional processing in anxiety. Cognit. Emot. 22 (6), 985–1018. https://doi.org/10.1080/02699930701597601.
Zeidner, M., 1998. Test Anxiety: the State of the Art. Plenum Press.
Zeidner, M., et al., 2005. Evaluation Anxiety. Guildford Press, London.
Zhang, W., et al., 2019. ERP evidence for inhibitory control deficits in test-anxious individuals. Front. Psychiatr. 10, 645. https://doi.org/10.3389/fpsyt.2019.00645.
Zhang, X., et al., 2018. Examination stress results in attentional bias and altered neural reactivity in test-anxious individuals. Neural Plast. 2018, 3281040 https://doi.org/10.1155/2018/3281040.