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Enhanced or impoverished recruitment of top-down attentional control of inhibition in test anxiety

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ABSTRACT

Controversy exists as to whether high test anxiety (HTA) individuals, when completing an inhibition task, increase or decrease top-down attentional control resources to maintain high task performance. In a flanker task experiment, individuals were confronted with a threat or no threat context in combination with a low or a high working memory load. The N2 measured top-down attentional control resource allocation. The results showed that, in comparison to low test anxiety (LTA) individuals, HTA individuals had larger N2 amplitudes in a no threat condition, especially for incongruent trials. Also, in a threat condition when under high working memory load, HTA individuals had smaller incongruent N2 amplitudes. These findings support the conclusion that HTA individuals tend to enhance recruitment of top-down attentional control of inhibition. Additionally, they may also fail to compensate for impaired inhibition as indicated by impoverished top-down attentional control resources when demands on attentional control are high.

1. Introduction

Past research has demonstrated that test anxiety in individuals increases the risk for the development of anxiety and depression disorders (Leadbeater, Thompson, & Gruppuso, 2012). Studies suggested that 15–22 percent of students exhibit high levels of test anxiety (Putwain & Daly, 2014; Thomas, Cassady, & Finch, 2018). Test anxiety refers to a situation-specific form of anxiety, with anxiety-related cognitive, behavioural, and affective characteristics elicited by test-related stimuli, especially stimuli referring to educational or evaluative settings (Zeidner, 1998). Importantly, test anxiety is known to be associated with impaired performance on academic achievement assessments (Putwain & Symes, 2018; Von der Embse, Jester, Roy, & Post, 2018). Attentional Control Theory (ACT) states that test anxiety impairs inhibition, a key element of the central executive function (Eysenck, Nazanin, Rita, & Calvo, 2007). Meanwhile, a large number of experimental studies have supported this statement (Ansari & Derakshan, 2011; Basten, Stelzel, & Fiebach, 2011; Berggren & Derakshan, 2013a; Derakshan & Eysenck, 2009; Eysenck & Derakshan, 2011; Eysenck, Nazanin et al., 2007; Pacheco-Unguetti, Acosta, Callejas, & Lupiáñez, 2010; Righi, Mecacci, & Viggiano, 2009; Savostyanov et al., 2009; Van den Bussche, Vanmeert, Aben, & Sasanguie, 2020).

However, the present literature is divided as it is unclear as to whether test anxiety is associated with enhanced or impoverished recruitment of top-down attentional control when completing an inhibition task, shortly referred to as “enhanced recruitment” and “impoverished recruitment”, respectively. The possibility of enhanced or impoverished recruitment define two opposing accounts in the literature, each of which are supported by different theories and evidences (Berggren & Derakshan, 2013a; Bishop, 2009; Eysenck & Derakshan, 2011; Eysenck, Nazanin et al., 2007).

The first account, enhanced recruitment, emerges from both Processing Efficiency Theory (PET) and ACT (Eysenck, 1992; Eysenck, Nazanin et al., 2007). Both PET and ACT propose that, in contrast with low test anxiety (LTA) individuals, high test anxiety (HTA) individuals make a higher effort to maintain high task performance, that is they display increased recruitment of top-down attentional control of inhibition. In other words, in contrast with LTA individuals, HTA individuals need to use more attentional control resources when completing the same experimental task. Numerous relevant behavioural, EEG and fMRI

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studies attested to the existence of such increase (Basten et al., 2011; Berggren & Derakshan, 2013b; Derakshan, Ansari, Hansard, Shoker, & Eysenck, 2009; Righi et al., 2009; Savostyanov et al., 2009; Sehlmeyer et al., 2010).

The second account gave rise to not just one, but two clearly distinct views, mainly depending on the extent to which high experimental demands on attentional control were also considered. A first view is proposed by Bishop who asserted that anxiety is correlated with an impoverished recruitment of top-down attentional control when performing the inhibition task (Bishop, 2009). Unfortunately, this view is exclusively based on experiments imposing low demands on attentional control. Our study context is fundamentally different in terms of the extent of the demand on attentional control. Indeed, our study context deals with test anxiety as manifested in educational or evaluative settings, which are characterized by high demands on attentional control. In contrast with LTA individuals, HTA individuals tend to be motivated to recruit greater attentional control resources to compensate for impaired efficiency when performing the inhibition task (Eysenck, Nazanin et al., 2007). ACT also proposed the possibility that anxious individuals may fail to compensate for impaired efficiency through enhanced effort and use of attentional control resources when overall task demands are in overload (Eysenck, Nazanin et al., 2007). But so far, no published research clarifies whether HTA individuals would show impoverished recruitment of top-down attentional control of individuals' inhibition when overall task demands are in overload. Our present study is positioned in close alignment with the second possible view asserting that test anxiety is associated with impoverished recruitment of top-down attentional control of individuals' inhibition in educational or evaluative settings.

More specifically, in our study, we proposed an integrated account asserting that, in contrast with LTA individuals, HTA individuals can enhance top-down attentional control resources to compensate for impaired inhibition when the available resources for attentional control are not limited. Additionally, when demands on attentional control are high, HTA individuals may also fail to effectively enhance effort and use attentional control resources to compensate for impaired inhibition, a failure that attests to impoverished of top-down attentional control resources of inhibition. As far as we know, to date, no experimental evidence is collected which supports this integrated account. However, our present study does provide a first step in compiling an evidence base for the integrated account.

In order to test the integrated account, we had to design an experiment which induces experimental settings characterized by limited or adequate available attentional control resources for inhibition. Thus, individuals had to perform an arrow flanker task as well as simultaneously complete either a low or high working memory load task in a test-related threat or a no threat condition. First, according to Lavie's load theory of selective attention (Lavie, Hirst, De Fockert, & Viding, 2004), increased working memory load reduces the available attentional control resources for performing the inhibition task, especially for high anxious individuals (Berggren, Richards, Taylor, & Derakshan, 2013; Qi et al., 2014; Spangler & Friedman, 2017). Second, test anxiety is a situation-specific form of anxiety (Zeidner, 1998). In contrast with LTA individuals, HTA individuals are more likely to allocate attentional control resources to threat-related internal (e.g., worrisome thoughts) or external (e.g., threatening task-irrelevant distractors) stimuli, especially in a test-related threat condition (Dong, De, Yu, & Zhou, 2016; Keogh & French, 2001; Putwain, Langdale, Woods, & Nicholson, 2011). Thus, when switching from a no test-related threat condition to a test-related threat condition, a substantial reduction of the available attentional control resources for HTA individuals is expected to be observed. Using the experimental manipulations introduced above, we were able to successfully induce experimental settings characterized by limited or adequate available attentional control resources for performing the inhibition task.

In addition, the flanker related evoked event-related potential (ERP) component N2 was used to measure top-down attentional control resource allocation. The N2 wave is a fronto-central stimulus-locked component having a latency of between 200 and 400 ms and is continuously monitored during individuals' conduct of the experimental trials (Folstein & Van Petten, 2008). The N2 amplitude is known to show the following pattern, it is larger in experimental conditions providing incongruent response options than in experimental conditions providing congruent response options (Folstein & Van Petten, 2008). Past studies showed that the N2 is conceived to be due to the nature of conflict monitoring processes and the role of top-down attentional control resource allocation in inhibition, which has been repeatedly used to measure cognitive effort in studies examining worry and anxiety-related emotions and inhibition (Folstein & Van Petten, 2008; Owens, Derakshan, & Richards, 2015; Righi et al., 2009; Sehlmeyer et al., 2010; Tillman & Wiens, 2011).

Above all, the main aim of this study was to test whether test anxiety is associated with enhanced or impoverished recruitment of top-down attentional control of individuals' inhibition. We hypothesized that HTA individuals are expected to differ from individuals not suffering from test anxiety, in that HTA individuals will recruit greater attentional control resources in order to maintain comparable task performance, at least when the available resources for attentional control are not limited. Thus, more specifically, we expected that HTA individuals would show larger N2 amplitudes than LTA individuals, especially in the following experimental condition: no test-related threat, and incongruent trials, both combined. However, for HTA individuals the resources available for attentional control are limited, especially in a threat condition when under high working memory load. We hypothesized that HTA individuals may also fail to effectively enhance effort and use of attentional control resources to compensate for impaired inhibition, a failure that attests to impoverished of top-down attentional control resources of inhibition. Thus, we also expected that HTA individuals would show smaller N2 amplitudes than LTA individuals, especially in the following experimental condition: test-related threat, high working memory load, and incongruent trials, all combined.

2. Methods

2.1. Participants

Initially, 442 students from Nanjing University, China, took part in a mass screening using the Chinese version of test anxiety scale (TAS). In line with conceptual underpinnings of the concept of test anxiety (Sarason, 1977), and in accordance with Newman (Newman, 1996), those participants scoring $>$20 on TAS were assigned to the HTA group; while those participants scoring $<$ 12 on TAS were assigned to the LTA group. Subsequently, only participants who scored high on test anxiety or low on test anxiety were chosen for further consideration. Finally, 50 HTA participants (mean age = 20.08 $\pm$ 1.47 years, 36 females) and 50 LTA participants (mean age = 20.68 $\pm$ 1.98 years, 41 females) were selected. All participants gave their written informed consent and were informed about their right to discontinue participation at any time. Two HTA participants assigned to the no test-related threat condition quit the experiment. So, eventually 98 participants participated in our present study. The experiment procedures were approved by the Ethics Committee of Department of Psychology, Nanjing University and carried out in accordance with the approved guidelines.

2.2. Assessment of test anxiety

The group of participants suffering (or not suffering from) test anxiety group was determined on the basis of scores on TAS. The Chinese version of TAS was used in the present study (Wang, 2001). For descriptive purposes, the Chinese version of Beck Depression Inventory II (BDI-II) was also administered to assess participants' depression (Beck, Steer, & Brown, 1996; Wang et al., 2011). In our present study, Cronbach's alpha is 0.80 for TAS, and 0.90 for BDI-II. Descriptives on TAS and BDI-II for both HTA and LTA participants are shown in Table 1.

2.3. Experimental procedure and stimuli

A dual task design was used. In this design, in every experimental trial, participants were required to jointly perform a working memory task and a flanker task. More specifically, the experimental procedure underlying one experimental trial proceeded as follows. As shown in Fig. 1, the trial started with a fixation cross which was displayed for 1 s, followed by a small or large memory set (i.e., an array with either one digit or six digits, each of which randomly drawn from the 10-element set: ["0", "1", … up to … "9"]) ; the memory set was shown and participants were instructed to try to provide the correct answer, that is to remember the 1 digit or, alternatively, the 6 digits. Then, another overlay array (i.e., a row always filled with six asterisks) masking just one or six digits was presented for 1 s. After that, a blank screen was shown for a randomized time between 1–1.5 s. Next, the five arrows comprising the flanker task were jointly presented for 0.3 s, including one centrally positioned target arrow and two flanked distractor arrows on each side (left and right) of the target arrow. There were two experimental conditions: (1) in the congruent condition (50 % chance, at random), the target arrow and the distractor arrows were all having the same orientation, and (2) in the incongruent condition (50 % chance, at random), the target arrow and distractor arrows were having a different orientation. Participants were instructed, by using their right hand, to indicate as quickly and accurately as possible the direction of the target arrow and press on the computer keyboard a button "J" (positioned on the left) if the target arrow pointed to the left or a button "K'' (positioned on the right) if the target arrow pointed to the right. Each arrow subtended a visual angle of 0.6° vertically and 0.8° horizontally. The distance between the arrows was 0.16°. After a 1.7 s delay, a memory probe started with only one digit. Participants were asked to press, on the computer keyboard using their left hand, the button "C'' if the memory probe letter was included in the memory set or (also using their left-hand) the "V"key if it was not included in the memory set. The memory probe was presented for 5 s or until the participant responded. The inter-trial interval was 0.5 s. All the stimuli were white and appeared on a black background.

2.4. Design and procedure

Twenty-five HTA and twenty-five LTA participants were randomly allocated to a test-related threat condition; twenty-three (i.e., twenty-five initially before two dropped out) HTA and twenty-five LTA participants were randomly allocated to a no test-related threat condition. Participants were seated comfortably in separate rooms about 70 cm away from a 21-inch screen. In a threat condition, participants were instructed to respond as quickly and accurately as possible in every experimental trial. And, participants were informed that: (1) the aim of the project was to measure cognitive ability; (2) the experimental task relates to levels of intelligence and can be used to predict educational performance outcome; and (3) personal results will be evaluated by members of the departmental teaching staff and compared with the results of other participants (Keogh & French, 2001; Putwain et al., 2011).

Table 1
The TAS and BDI-II scores in each experimental group (data are expressed as mean ± standard error, M ± SE).

	No threat		Threat	
	LTA	HTA	LTA	HTA
TAS	8.72 ± 0.68	24.70 ± 0.71	8.71 ± 0.70	25.00 ± 0.70
BDI-II	5.92 ± 1.37	12.78 ± 1.43	6.08 ± 1.37	13.76 ± 1.37

Note: No threat: No test-related threat; Threat: Test-related threat; HTA: High test anxiety; LTA: Low test anxiety.

In the no threat condition, participants were only instructed to respond as quickly and accurately as possible in every experimental trial. The formal experiment consisted of four blocks. Each block consisted of 80 trials. The conditions of working memory load were blocked, meaning that every block consisted of 80 trials, all of which were characterized by either a low or a high working memory load. Participants performed the experimental task in the following block sequence: high/low/high/low working memory load, and the other half performed the alternate sequence: low/high/low/high working memory load. Before conducting the formal experiment, the participants conducted 10 practice experimental tasks in both low working memory load and high working memory load.

2.5. EEG data collection and analysis

EEG data were collected using 32 Ag-AgCl scalp electrodes placed according to the International 10–20 system (pass-band: 0.01–100 Hz; sampling rate: 500 Hz). The signals were amplified using Neuroscan (USA) amplifiers. Prior to recording, impedances were below 10 kOhm. During recording, the ground lead was located at AFz and the right mastoid was set as a reference.

EEG data were processed using EEGLAB (Delorme & Makeig, 2004), an open source toolbox running in the MATLAB environment. Continuous EEG data were filtered with a 30 Hz low-pass filter and a 0.1 Hz high-pass filter and were re-referenced to the average mastoids. EEG epochs were extracted using a window analysis time of 1200 ms (200 ms pre flanker stimulus and 1000 ms post flanker stimulus), and were baseline corrected using the pre-stimulus interval. Trials with large drift were removed manually, then trials contaminated by eyeblinks and movements were corrected using the independent component analysis (ICA) algorithm. Across participants, 3 ± 2 ICs of ocular artifacts were identified and removed from the EEG signals. Because the cognitive process for incorrect trials is mixed, only correct trials were included in final analysis. And, trials with amplitude values exceeding ± 75 μV at any electrode were rejected. Finally, the numbers of congruent trials in low load were 67.81 ± 10.34; the numbers of incongruent trials in low load were 66.32 ± 9.44; the numbers of congruent trials in high load were 68.92 ± 7.81; the numbers of incongruent trials in high load were 66.40 ± 7.65. Consistent with previous research (Folstein & Van Petten, 2008) and based on visual inspection of ERP waveforms, N2 amplitudes were extracted as the average of 15 ms pre-peak to 15 ms post-peak negative amplitude between 230 ms and 350 ms at FCz electrode site and used for further analysis.

2.6. Statistical analysis

All statistical analyses were carried out in SPSS 17.0 statistical analysis package (SPSS Inc., New York, USA). In the working memory task, participants' accuracy was analyzed using a three-way mixed analysis of variance (ANOVA) with test anxiety (high and low) and test-related threat (threat and no threat) as between-subject factors, and with working memory load (high vs. low) as within-subject factor. In the flanker task, participants' reaction times (RTs), accuracy and N2 amplitude, were analyzed separately using a four-way mixed ANOVA with test anxiety (high and low) and test-related threat (threat and no threat) as between-subject factors, and with congruency (congruent vs. incongruent) and working memory load (high vs. low) as within-subjects factors. To correct for a possible violation of the "sphericity assumption", the Greenhouse-Geisser correction was applied. Multiple comparisons were adjusted using a Bonferroni correction. In the study significance is operationally defined as a p value falling below .05, and marginal significance as a p value of .05 or higher, but lower than .10.

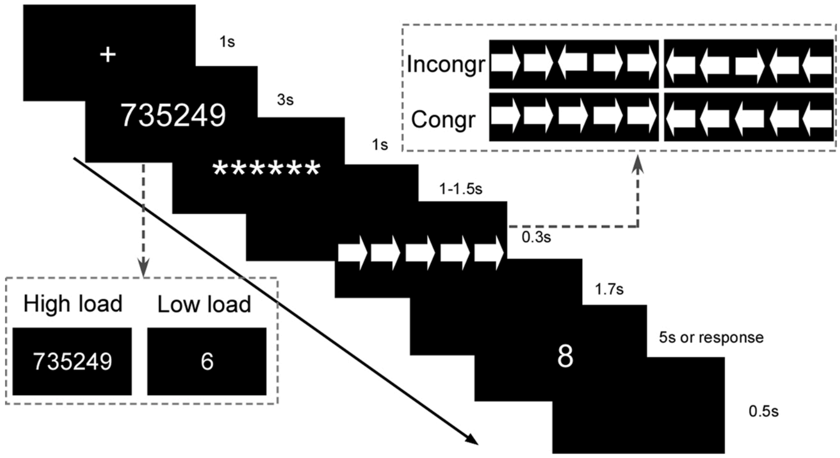

Fig. 1. Task design. An example of a congruent trial in a condition of high working memory load.
Note: High load: High working memory load; Low load: Low working memory load; Incongr: Incongruent; Congr: Congruent.

3. Results

3.1. Working memory task

The outcomes of probe accuracy are shown in Table 2. Because participants were informed that only accuracy and thus not RTs matters in the conduct of the memory probe task, only probe accuracy was analysed.

The results showed that a significant main effect was found for test anxiety, $F(1, 94) = 6.66, p = .01, \eta_p^2 = .07$, 95 % CI [0.002, 0.017], which attested to a lower accuracy for HTA participants (0.959 ± 0.003) than for LTA participants (0.969 ± 0.001). And, no other significant effect was found.

3.2. Flanker task

3.2.1. Behavioral results

The outcomes of RTs and accuracy are shown in Table 3. Only RTs for correct trials were considered. RTs exceeding 3 SD of the participant mean scores were also discarded.

3.2.1.1. Reaction Times (RTs). RTs outcomes revealed multiple significant effects. First, a significant main effect was found for congruency, $F(1, 94) = 642.65$, $p < .001$, $\eta_p^2 = .87$, 95 % CI [57.77, 67.58], which attested to faster RTs for congruent trials (454.04 ± 6.92) than for incongruent trials (516.71 ± 7.37). Second, a significant main effect was found for test-related threat, $F(1, 94) = 10.08$, $p = .002$, $\eta_p^2 = .10$, 95 % CI [16.75, 72.65], which attested to faster RTs in the threat condition (463.03 ± 9.85) compared to the no threat condition (507.73 ± 10.06). Third, the interaction between congruency and working memory load turned out to be significant, $F(1, 94) = 17.62, p < .001, \eta_p^2 = .16$; follow-up analyses showed that, only incongruent (and thus not congruent) RTs were found to be significantly higher in high working memory load (519.50 ± 7.27) compared to low working memory load (513.93 ± 7.60, $p = .007$, 95 % CI [1.56, 9.56]).

3.2.1.2. Accuracy. Accuracy outcomes revealed several significant effects. First, a significant main effect was found for congruency, $F(1, 94) = 63.19, p < .001, \eta_p^2 = .40$, 95 % CI [0.015, 0.025], which attested to a lower accuracy for incongruent trials (0.977 ± 0.003) than for congruent trials (0.997 ± 0.001). Second, the interaction between congruency and working memory load turned out to be significant, $F(1, 94) = 4.61$, $p = .03$, $\eta_p^2 = .05$; follow-up analyses showed that higher accuracy was obtained in incongruent trials with low memory load (0.980 ± 0.003) than in incongruent trials with high memory load (0.975 ± 0.003, $p = .046$, 95 % CI [0.000, 0.001]). Third, the interaction between test anxiety, test-related threat, and working memory load was also significant, $F(1, 94) = 4.45$, $p = .038$, $\eta_p^2 = .05$; follow-up analyses showed that, in the threat condition, LTA participants showed higher accuracy in incongruent trials with low memory load (0.991 ± 0.004) than in incongruent trials with high memory load (0.982 ± 0.003, $p = .004$, 95 % CI [0.003, 0.014]).

3.2.2. Amplitude of ERP component N2

The grand means of the ERP waveforms and the topographic scalp maps are shown in Fig. 2.

N2 amplitude outcomes revealed several significant effects. First, a significant main effect was found for congruency, $F(1, 94) = 6.45$, $p = .01$, $\eta_p^2 = .01$, 95 % CI [0.10, 0.82], which attested to a larger N2 amplitude for incongruent trials (−3.75 ± 0.39) than for congruent (−3.29 ± 0.38) trials. Second, a significant main effect was found for working memory load, $F(1, 94) = 29.99$, $p < .001$, $\eta_p^2 = .24$, 95 % CI [0.71, 1.51], which attested to a larger N2 amplitude associated with high memory load (−4.08 ± 0.39) than with low memory load (−2.97 ± 0.39). Third, the interaction between test anxiety and test-related threat turned out to be significant, $F(1, 94) = 8.53$, $p = .004$, $\eta_p^2 = .08$; follow-up analyses showed that: in the no threat condition, HTA participants (−5.13 ± 0.78) produced a significant larger N2 amplitude than LTA participants (-2.45 ± 0.75, $p = .015$, 95 % CI [0.54, 4.82]). Fourth, the (higher-order) interaction between test anxiety, test-related threat, working memory load and congruency was significant, $F(1, 94) = 4.35$, $p = .04$, $\eta_p^2 = .04$; follow-up analyses showed that (to allow adequate interpretation crucial non-significant effects are also reported): (1) in the combined no threat and low working memory load condition, (1a) HTA participants (−4.69 ± 0.87) produced a significantly larger incongruent N2 amplitude than LTA participants (−1.89 ± 0.84, $p = .02$, 95 % CI [0.41, 5.20]), (1b) HTA participants (−4.24 ± 0.87) produced a

Table 2
Working memory probe accuracy in each experimental group (data are expressed as mean ± standard error, M ± SE).

		Accuracy	
		Low load	High load
No threat	LTA	0.969 ± 0.004	0.966 ± 0.005
	HTA	0.959 ± 0.004	0.957 ± 0.005
Threat	LTA	0.971 ± 0.004	0.969 ± 0.005
	HTA	0.964 ± 0.004	0.957 ± 0.005

Note: No threat: No test-related threat; Threat: Test-related threat; High load: High working memory load; Low load: Low working memory load; HTA: High test anxiety; LTA: Low test anxiety.

Table 3
Flanker RTs and accuracy in each experimental group (data are expressed as mean ± standard error, M ± SE).

			Incongruent		Congruent	
			RTs	Accuracy	RTs	Accuracy
No threat	Low load	LTA	549.70 ± 15.04	0.997 ± 0.006	497.85 ± 14.48	0.998 ± 0.001
		HTA	522.75 ± 15.68	0.978 ± 0.007	460.22 ± 15.10	0.998 ± 0.001
	High load	LTA	552.50 ± 14.37	0.984 ± 0.006	487.40 ± 13.19	0.998 ± 0.002
		HTA	529.38 ± 14.99	0.973 ± 0.006	462.01 ± 13.75	0.997 ± 0.002
Threat	Low load	LTA	490.61 ± 15.04	0.983 ± 0.006	429.62 ± 14.48	0.999 ± 0.001
		HTA	492.67 ± 15.04	0.971 ± 0.006	431.69 ± 14.48	0.995 ± 0.001
	High load	LTA	495.58 ± 14.37	0.967 ± 0.006	427.67 ± 13.19	0.995 ± 0.001
		HTA	500.53 ± 14.37	0.974 ± 0.006	435.88 ± 13.19	0.996 ± 0.002

Note: No threat: No test-related threat; Threat: Test-related threat; High load: High working memory load; Low load: Low working memory load; HTA: High test anxiety; LTA: Low test anxiety; RTs: Reaction times.

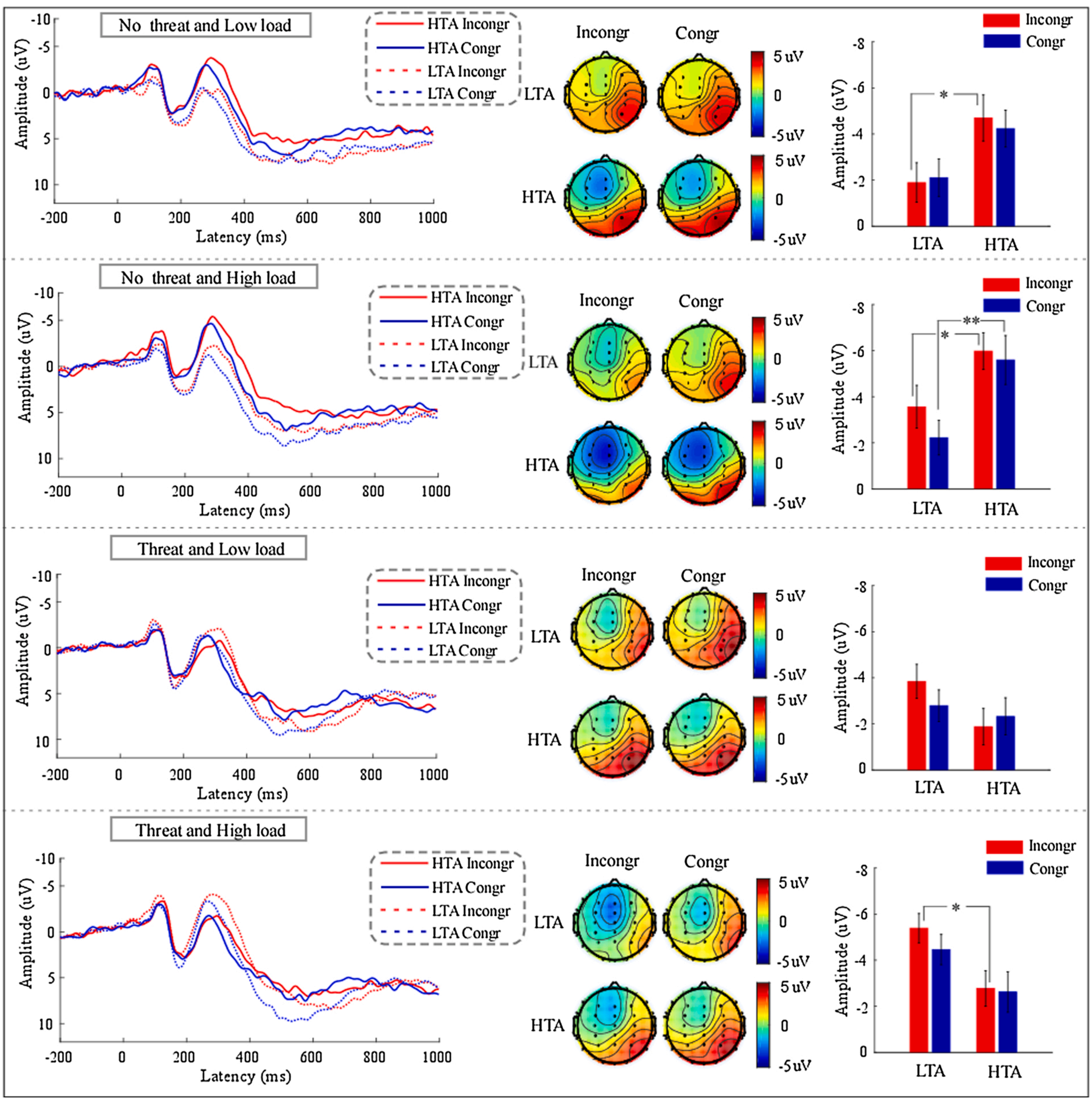

Fig. 2. The grand means of N2's waveforms across different conditions for LTA and HTA individuals at electrode site FCz. Additionally, the topography of N2 (windows: 230-350 ms), and mean values for N2 amplitude are given.
Note: No threat: No test-related threat; Threat: Test-related threat; High load: High working memory load; Low load: Low working memory load; HTA: High test anxiety; LTA: Low test anxiety; Incongr: Incongruent; Congr: Congruent; $p^* < .05$; $p^{**} < .01$.

marginally larger congruent N2 amplitude than LTA participants (−2.10 ± 0.77, p = .057, 95 % CI [−0.07, 4.34]); (2) in the combined no threat and high working memory load condition, (2a) HTA participants (−5.98 ± 0.81) produced a significantly larger incongruent N2 amplitude than LTA participants (−3.56 ± 0.78, p = .034, 95 % CI [0.18, 4.66]), (2b) HTA participants (−5.59 ± 0.87) produced a significantly larger congruent N2 amplitude than LTA participants (−2.22 ± 0.83, p = .006, 95 % CI [0.10, 5.76]); (3) in the combined threat and low working memory load condition, (3a) HTA participants (−1.88 ± 0.84) did not produce a significantly different incongruent N2 amplitude than LTA participants (−3.84 ± 0.84, p = .10), (3b) HTA participants (−2.32 ± 0.78) did not produce a significantly different congruent N2 amplitude than LTA participants (−2.79 ± 0.77, p = .67); (4) in the combined threat and high working memory load condition, (4a) HTA participants (−2.78 ± 0.78) produced a significant smaller incongruent N2 amplitude than LTA participants (−5.39±0.78, p = .02, 95 % CI [0.42, 4.80]), and (4b) HTA participants (−2.62 ± 0.83) did not produce a significant different congruent N2 amplitude than LTA participants (-4.46 ± 0.83, p = .12).

4. Discussion

To the best of our knowledge, the present study is the first to make a direct, experiment-wise evaluation of multiple possibilities, being the possibility that test anxiety impairs inhibition and two other possibilities, namely that, in contrast with LTA individuals, HTA individuals display enhanced or impoverished recruitment of top-down attentional control of inhibition. To make this evaluation we assessed EEG activity while HTA and LTA individuals performed a flanker task involving both a low or high working memory task, each of which includes both congruent and incongruent conditions, and implemented within both a threat and a no threat experimental condition. The ERP component N2 was used to assess top-down attentional control resource allocation. Fully consistent with all our hypotheses, the results showed that, (1) in the combined no threat and low working memory load condition, HTA individuals produced larger incongruent N2 amplitudes than LTA individuals; (2) in the combined no threat and high working memory load condition, HTA individuals produced larger incongruent and congruent N2 amplitudes than LTA individuals; (3) in the combined threat and low working memory load condition, HTA individuals did not produce significantly different incongruent and congruent N2 amplitudes than LTA individuals; and (4) in the combined threat and high working memory load condition, HTA individuals produced smaller incongruent N2 amplitudes than LTA individuals.

Our first hypothesis stated that, unlike LTA individuals, HTA individuals recruit greater attentional control resources and make more efforts to maintain high task performance, when the available resources for attentional control are not limited. In support of our first hypothesis our study results showed that, in a no threat condition, in contrast with LTA individuals, HTA individuals revealed a larger N2 amplitude when conducting the flanker task, in particular a larger incongruent N2 amplitude. Registration of the N2 amplitude in flanker trials enabled the study of neurological activity in the anterior cingulate cortex (ACC) and other frontal-lobe mediated conflict monitoring processes in attentional control (Folstein & Van Petten, 2008; Kerns et al., 2004). The registration of the flanker N2 amplitude over and above the monitoring of behavioural performance (e.g., RTs) is beneficial as, unlike individuals' behavioural performance, the flanker N2 amplitude is informative about individuals' cognitive processes, more specifically cognitive control ability required for performing the experimental task (Tillman & Wiens, 2011). Our study results supported ACT's assumption that HTA individuals enhance recruitment of top-down attentional control resources to keep task performance at levels which are comparable to those of LTA individuals (Derakshan & Eysenck, 2009; Eysenck, Derakshan, Santos, & Calvo, 2007). Many prior experimental studies relying on inhibition measurement paradigms other than a flanker task (e.g., the emotional flanker task, the GoNogo task, and the color word Stroop task), showed that, in a no threat condition, individuals scoring high on both the trait worry and anxiety show enhanced attentional control-related neural activity of inhibition processing. For example, scholars such as Owens and colleagues, who relied on an emotional flanker task and examined individuals high versus low on worry, showed that, in contrast with individuals scoring low on worry, individuals scoring high on worry produced a larger N2 amplitude (Owens et al., 2015). Additionally, also some other scholars, who relied on the GoNogo task and examined individuals diagnosed high versus low on the trait anxiety or an anxiety disorder, showed that, in contrast with individuals low on anxiety, individuals high on anxiety produced a larger N2 amplitude in Nogo trials (Ruchsow et al., 2007; Savostyanov et al., 2009; Sehlmeyer et al., 2010). In addition, Basten et al. (2011) who relied on an experimental color word Stroop task in combination with fMRI and examined individuals high on trait anxiety, showed increased dorsolateral PFC activity, for incongruent relative to congruent distractor Stroop trials (Basten et al., 2011). The increased dorsolateral PFC activity and increased N2 amplitude are indicative of an increase in the attentional control resources used by high anxious individuals when performing the experimental task.

Our second hypothesis stated that, in contrast with LTA individuals, HTA individuals display impoverished recruitment of top-down attentional control resources in settings characterized by high demands on attentional control in high working memory load and a threat condition. Relevant earlier study show that, in a threat condition, the consumption of attentional control resources is more easy for HTA individuals than for LTA individuals (Keogh & French, 2001; Putwain et al., 2011). Taking into account that test anxiety is a situation-specific form of anxiety (Zeidner, 1998), HTA individuals are expected to display high levels of worry and concerns about self-evaluative aspects of failure in educational and evaluative situations. Thus, being confronted with a threat, HTA individuals are expected to experience an overload in terms of attentional resources used for inhibition tasks. In line with Lavie's load theory of selective attention (Lavie et al., 2004), the switch from low to high load confronts HTA individuals with a further reduction of attentional control resources available for inhibition tasks (Berggren et al., 2013; Qi et al., 2014; Spangler & Friedman, 2017). Thus, HTA individuals gradually move to a state in which it becomes impossible to compensate for reduced task performance in an inhibition task. In other words, compensatory strategies such as enhanced effort and the use of attentional control resources are no longer successful. Taking also into account that as far as task performance is concerned, incongruent trials require more attentional control resources than congruent trials, it should not come as a surprise that the difference between HTA and LTA individuals is most outspoken in incongruent trials as opposed to congruent trials (Tillman & Wiens, 2011). With such study results, as obtained from a carefully designed experiment, our study made a clear contribution, namely the provision of experimental support for the existence of the phenomenon of impoverished top-down attentional control, typically observed when test anxiety individuals inhibit tasks in a condition in which the demands on attentional control are in overload. Support for the existence of this phenomenon is beneficial as it helps explaining commonly encountered difficulties in educational or evaluative settings, typically characterized by high demands on attentional control.

By relying on existing evidence as extracted from two identified accounts and the conduct of a flanker task experiment we were able to reveal how, at the neurological level, test anxiety in individuals impairs their inhibition. Our study shows that, in order to maintain high task performance, HTA individuals show a tendency to use compensatory strategies such as enhanced effort and use of attentional control resources. In other words, HTA individuals display increased recruitment of top-down attentional control of inhibition. However, our study also shows that such compensatory strategies are not always effective. Especially when: (1) the available attentional control resources are limited or, even worse, (2) the demands on attentional control are in overload, HTA individuals can no longer effectively compensate for impaired efficiency through enhanced effort and use of attentional control resources. One must, therefore, conclude that, in such experimental conditions, HTA individuals display impoverished top-down attentional control of inhibition.

As all other experimental studies, our study has some limitations as well. First, the sample size relied on in this study is small, which leads to low statistical power and low reproducibility (Button et al., 2013; Simonsohn, 2015). So, future replication studies using a larger sample size would be most welcome. Second, unlike our ERP results, our behavioural results were not aligned with our hypotheses. Previous behavioural studies showed that, in a no threat condition, in contrast with low anxiety individuals high anxiety individuals show longer RTs to perform the inhibition task (Derakshan & Eysenck, 2009; Eysenck & Derakshan, 2011; Eysenck, Nazanin et al., 2007). On the basis of this previous research one might be inclined to believe that longer RTs for HTA individuals (when compared with LTA individuals) should be anticipated, and that such anticipated pattern of group differences in RTs also attests to the existence of increased recruitment of top-down attentional control of inhibition. However, our behavioural results were in discordance with our hypotheses. The analysis of RTs in our study failed to replicate the anticipated pattern of group differences in RTs. Such failure to replicate an anticipated pattern of results could, however, be expected as some researchers stated that anticipated patterns of group differences in RTs may be unrealistic as RTs are found to be an inadequate measure of processing efficiency of inhibition (Eysenck & Derakshan, 2011; Righi et al., 2009; Savostyanov et al., 2009; Sehlmeyer et al., 2010). In addition, several relevant studies showed that an enhanced anxiety level was not associated with longer RTs when performing inhibition tasks (Basten et al., 2011; Righi et al., 2009; Sehlmeyer et al., 2010). After all, as RTs serve as an outcome measure in an experimental context, it does not reflect attentional control resource allocation of inhibition (Tillman & Wiens, 2011). In sum, the discordance between RT results and our hypotheses may be logical as adequate measurement of attentional resource allocation of inhibition can only be obtained through reliance on adequate measurement of relevant neural activity and not on behavioural measures. In addition to RTs, our accuracy results also point towards a discordance between our study results and our hypotheses. In contrast to HTA individuals, only LTA individuals had lower incongruent accuracy when switching from low to high working memory load in the threat condition. We speculated that the main reason for this accuracy difference between HTA and LTA individuals may be caused by our small sample size. Third, the results showed that increased working memory load failed to produce lower working memory accuracy, and that both threat and load manipulations failed to disrupt performance in the HTA group to a greater extent than in the LTA group. The most likely reason for these failures is the occurrence of a “ceiling effect” which may have been caused by the nature of our experimental instructions, namely the fact that individuals learned that only accuracy and thus not RTs mattered, and that they would have enough time to complete the working memory task in all experimental conditions. A final limitation of our study pertains to differences in the level of depression as observed across HTA and LTA participants. Although BDI-II scores did not attest to a major depression in any participant, HTA individuals were found to display higher levels of depression than LTA individuals. This group difference is worrisome as differences in level of depression rather than test anxiety may be partially responsible for some of the behavioural and neurological differences observed across these groups. Future replication studies could be designed such that, by design, they totally exclude the possibility that cross-group differences in depression confound cross-group differences ascribed to prior group differences in test anxiety.

In sum, the present study only relied on the ERP indicator N2 to examine the extent to which HTA individuals (as opposed to LTA individuals) can enhance or reduce top-down attentional control resources while performing the inhibition task. Our study demonstrated that HTA individuals can enhance top-down attentional control resources when the available resources for attentional control are not limited. Additionally, when the available attentional control resources are limited or experimental task demand is in overload, HTA individuals typically fail to effectively enhance effort and use attentional control resources to compensate for impaired inhibition, a failure that attests to impoverished of top-down attentional control resources of inhibition.

Declaration of Competing Interest

The authors report no declarations of interest.

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