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Research article

Relation between spontaneous electroencephalographic theta/beta power ratio and test anxiety

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ABSTRACT

Test anxiety is associated with impaired attentional control, and spontaneous electroencephalography (EEG) theta/beta power ratio (TBR) may reflect the cortical–subcortical interactions involved in attentional control. The present study investigated how test anxiety influences spontaneous EEG TBR. Individuals undertook a 10-minute Raven's intelligence test. Spontaneous EEG data were recorded before and after the test and subsequently analyzed. TAS score showed a significant positive correlation with parietal EEG TBR before the test. Individuals with high test anxiety exhibited a significantly larger parietal EEG TBR than did individuals with low test anxiety, both before and after the test. The findings suggest that parietal spontaneous EEG TBR is related to test anxiety and can distinguish between individuals with high and low test anxiety.

1. Introduction

Test anxiety is a situation-specific form of trait anxiety [1]. Previous studies have suggested that 15%–22% of the student population experiences high levels of test anxiety [2,3]. High test anxiety increases the risks of anxiety and depression disorders [4]. Electroencephalography (EEG), an accessible and cost-effective method for investigating neural correlates of test anxiety, promotes the understanding of test anxiety's etiology. In particular, spontaneous theta/beta power ratio (TBR), which is obtained by dividing the theta band (4–8 Hz) power by the beta band (14–30 Hz) power, may reflect a neural correlate of test anxiety [5,6].

Spontaneous TBR supposedly indicates cortical – subcortical interactions, and numerous studies have suggested its negative correlations with attentional control and trait anxiety [7–10]. Research has demonstrated that TBR is elevated in individuals with attention deficit/hyperactivity disorder (ADHD) [9,11,12]. Previous studies have demonstrated that individuals with high TBR had low trait attentional control and impaired response inhibition when presented with fearful faces in an emotional go/no-go task [8]. Additionally, low frontal TBR predicts resilience against stress-induced reductions of attentional control [13]. TBR is a marker of attentional control over emotional information [10,14].

The defining feature of test anxiety is worrisome and negative self-statements concerning failure and one's competence [1]. Processing efficiency theory argues that worry can consume the limited attentional resources of working memory [15]. Furthermore, attentional control theory (ACT) suggests that test anxiety impairs attentional control of central executive functions [16–18]. Previous studies employing event-related potentials (ERP) and functional magnetic resonance imaging (fMRI) measures have shown that the impaired attentional control associated with test anxiety may be related to abnormal neural activity during task performance [19,20]. However, no research clearly explains how test anxiety influences spontaneous TBR.

Hua and Zhou found no significant frontal TBR difference between individuals with high and low test anxiety [21]. However, their study had two obvious limitations. First, they focused only on the fontal site, but the abnormal neural activity associated with high test anxiety may be not just reflected in the fontal site [22]. Second, because test anxiety is stress sensitive, individuals with high test anxiety have worrisome thoughts and concerns stemming from self-perceived failure, especially when dealing with exam stress [1,23]. Hua and Zhou have not considered the influence of exam stress. Putman, P., et al. found that the frontal theta/beta ratio moderates the deleterious effects of cognitive performance anxiety like anxious stress on state attentional control [13]. However, they measured the trait anxiety and self-report state anxiety,

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and found that there were no significant correlations between anxiety measures (trait anxiety and self-report state anxiety) and frontal theta/beta ratio. Thus, no research clearly explains how test anxiety influences spontaneous TBR.

To fill the gaps, the present study examined whether TBR is related to test anxiety by focusing not only on the frontal electrode site but also the central and parietal sites. Unlike previous studies, individuals were asked to undertake a 10-minute Raven's intelligence test, and 6-minute spontaneous EEG data were recorded before and after the test and analyzed. We hypothesized that, (1) TAS score would show a significant positive correlation with TBR before the test; (2) high test anxiety individuals would present elevated TBR, especially after the test; additionally, we expected that the theta and beta powers of high and low test anxiety individuals were not significantly different.

2. Method

2.1. Participants

Test anxiety was based on Test Anxiety Scale (TAS) scores [24]. In total, 49 high test anxiety participants and 44 low test anxiety participants were selected from Nanjing University in China. All participants were informed of their right to discontinue participation at any time and gave their written informed consent. The experiment procedures were approved by the Ethics Committee of the Department of Psychology at Nanjing University and were conducted in accordance with approved guidelines. Because of poor-quality recordings and incomplete data, 6 high test anxiety participants and 11 low test anxiety participants were excluded. Finally, 43 high test anxiety participants (TAS scores = 24.95 ± 4.28, mean age = 20.51 ± 1.68 years, 24 women) and 33 low test anxiety participants (TAS score = 7.76 ± 2.37, mean age = 21.06 ± 1.85 years, and 21 women) were included in the present study.

2.2. Materials

2.2.1. Test anxiety scale

Test anxiety was measured using the TAS [24]. The TAS consists of 37 items (0 = no, or 1 = yes), where higher scores indicate higher levels of test anxiety (scores range from 0 to 37). To adhere to the conceptual underpinnings of test anxiety and follow Newman's recommendations [25], participants scoring >20 on the TAS were assigned to the high test anxiety group, and those scoring <12 on the TAS were assigned to the low test anxiety group. The Chinese version of TAS was adapted by Caikang Wang, and the reliability and validity were satisfying [26]. The Cronbach's alpha was 0.84 in the present study.

2.2.2. Raven's intelligence test

Raven's Advanced Progressive Matrices (APM) measures general intelligence. The APM consists of two sets of items: Set I, which includes 12 items usually administered as a training set to familiarize the respondents with the problems; and Set II, which includes 36 items. In the present study, 1–18 items selected from Set II were used.

2.3. Design and procedure

Participants were seated comfortably in separate rooms approximately 70 cm from a 21-in screen. First, 6 min of spontaneous EEG data were recorded. During the EEG recording, the participants were asked to view a fixation cross at the center of the computer screen and were instructed to open and close their eyes, alternating every minute. Thereafter, first, the participants were asked to answer 18 Raven's intelligence test questions within 10 min, as past research has shown that the Raven's intelligence test can successfully induce the participants' feeling of stress [27]. Second, the participants were informed that their tests would be evaluated by departmental staff members, and their results would be compared with those of other students [23,28]. By using the above methods, the participants are expected to be stressed, especially for high test anxiety participants. After the test, another 6 min of spontaneous EEG data were recorded.

2.4. EEG data collection and analysis

The EEG data were recorded using 32 Ag–AgCl scalp electrodes placed according to the International 10–20 system (passband: 0.01–100 Hz, sampling rate: 500 Hz). The signals were amplified using Neuroscan (USA) amplifiers. Prior to recording, impedances were below 10 kΩ. During recording, the ground lead and reference were both located at AFz.

EEG data were processed using EEGLAB [29], an open-source toolbox that runs 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. Furthermore, the continuous EEG data were segmented into 1000-ms epochs. Trials with large drift were manually removed, then trials contaminated by eye blinks and motion artifacts were corrected using an independent component analysis algorithm. EEG epochs with amplitudes exceeding ±75 μV at any electrode were rejected. EEG signals were transformed to the frequency domain using the fast Fourier transform (Welch algorithm, no phase shift, 0.9766-Hz frequency resolution), yielding an EEG spectral power ranging from 1 to 30 Hz. Absolute spectral power was computed for the theta (4 − 8 Hz) and beta (14 − 30 Hz) band. Subsequently, TBR was calculated. The resultant values were natural-log-transformed to normalize the data. The spectral power obtained from the frontal (Fz), central (Cz), and parietal (Pz) electrodes was analyzed.

2.5. Statistical analysis

To examine the correlation between TAS score and TBR at frontal, central and parietal site, measured before the test for all participants, because the TAS score data were not normally distributed (Kolmogorov-Smirnov normality test, $p < 0.001$), Spearman correlations were used. We performed two-way mixed analyses of variance (ANOVAs) on Ln theta, Ln beta or Ln TBR with test phase (before or after) as the within-subject factor and test anxiety (high or low) as the between-subject factor. When the assumption of sphericity was violated, a Greenhouse–Geisser correction was applied. Multiple comparisons were adjusted with Bonferroni correction. All statistical analyses were conducted using the SPSS 17.0 statistical analysis package (SPSS Inc., New York, NY, USA).

3. Results

EEG data are presented in Table 1.

3.1. TAS score and TBR before the test

As shown in Fig. 1, TAS score showed a significant positive correlation with parietal TBR ($r = 0.246$, $p = 0.03$), but not significant with frontal TBR ($r = 0.217$, $p = 0.06$), and central TBR ($r = 0.215$, $p = 0.06$).

3.2. Effects of test on TBR for high and low test anxiety participants

3.2.1. Frontal

Theta: The results revealed a significant main effect of test phase, $F(1, 74) = 10.12$, $p = 0.002$, $\eta_p^2 = 0.12$, with smaller theta power for the before phase(1.76 ± 0.36) than for the after phase (1.85 ± 0.39). Test anxiety had no significant main effect, $F(1, 74) = 0.10$, $p = 0.75$, $\eta_p^2 = 0.001$. No significant interaction effect was found between test phase and test anxiety, $F(1, 74) = 0.56$, $p = 0.46$, $\eta_p^2 = 0.008$.

Table 1
EEG data in each experimental group (data are expressed as mean ± standard deviation, M ± SD).

		Pre test			Post test		
		Ln theta power	Ln beta power	Ln theta/beta	Ln theta power	Ln beta power	Ln theta/beta
HTA (N = 43)	Fz	1.76 ± 0.37	−0.12 ± 0.34	1.78 ± 0.29	1.87 ± 0.45	0.07 ± 0.40	1.80 ± 0.32
	Cz	1.82 ± 0.34	0.08 ± 0.33	1.74 ± 0.30	1.90 ± 0.41	0.10 ± 0.39	1.80 ± 0.32
	Pz	1.62 ± 0.33	0.17 ± 0.43	1.44 ± 0.35	1.69 ± 0.41	0.17 ± 0.44	1.51 ± 0.35
LTA (N = 33)	Fz	1.75 ± 0.34	0.10 ± 0.38	1.65 ± 0.37	1.82 ± 0.30	0.14 ± 0.31	1.68 ± 0.30
	Cz	1.79 ± 0.36	0.19 ± 0.36	1.60 ± 0.39	1.84 ± 0.33	0.18 ± 0.33	1.67 ± 0.31
	Pz	1.57 ± 0.34	0.33 ± 0.40	1.25 ± 0.40	1.65 ± 0.35	0.30 ± 0.40	1.34 ± 0.35

Notes: HTA: high test anxiety participants; LTA: low test anxiety participants.

Beta: The results revealed a significant main effect of test phase, $F(1, 74) = 5.27$, $p = 0.025$, $\eta_p^2 = 0.066$, with a smaller beta power for the before phase (0.04 ± 0.37) than for the after phase (0.10 ± 0.36). Test anxiety had no significant main effect, $F(1, 74) = 1.46$, $p = 0.23$, $\eta_p^2 = 0.019$. No significant interaction effect was found between test phase and test anxiety, $F(1, 74) = 0.72$, $p = 0.40$, $\eta_p^2 = 0.01$.

TBR: The results revealed no significant main effect for test phase or test anxiety, $F(1, 74) = 1.20$, $p = 0.28$, $\eta_p^2 = 0.016$, and $F(1, 74) = 3.02$, $p = 0.086$, $\eta_p^2 = 0.039$, respectively. No significant interaction effect was found between test phase and test anxiety, $F(1, 74) = 0.005$, $p = 0.94$, $\eta_p^2 < 0.001$.

3.2.2. Central

Theta: The results revealed a significant main effect for test phase, $F(1, 74) = 5.92$, $p = 0.017$, $\eta_p^2 = 0.07$, with a smaller theta power for the before phase (1.81 ± 0.40) than for the after phase (1.87 ± 0.44). Test anxiety had no significant main effect, $F(1, 74) = 0.29$, $p = 0.59$, $\eta_p^2 = 0.004$. No significant interaction effect was found between test phase and test anxiety, $F(1, 74) = 0.37$, $p = 0.55$, $\eta_p^2 = 0.005$.

Beta: The results showed no significant main effect for test phase or test anxiety, $F(1, 74) = 0.04$, $p = 0.84$, $\eta_p^2 = 0.001$, and $F(1, 74) = 1.43$, $p = 0.24$, $\eta_p^2 = 0.02$, respectively. No significant interaction effect was found between test phase and test anxiety, $F(1, 74) = 0.77$, $p = 0.38$, $\eta_p^2 = 0.01$.

TBR: The results revealed a significant main effect for test phase, $F(1, 74) = 6.14$, $p = 0.016$, $\eta_p^2 = 0.076$, with a smaller TBR for the before phase (1.67 ± 0.35) than for the after phase (1.73 ± 0.32). A marginally significant main effect was found for test anxiety, $F(1, 74) = 3.57$, $p = 0.062$, $\eta_p^2 = 0.046$, with a larger TBR for high test anxiety participants (1.78 ± 0.30) than for low test anxiety participants (1.63 ± 0.34). No significant interaction effect was found between test phase and test anxiety, $F(1, 74) = 0.06$, $p = 0.81$, $\eta_p^2 = 0.001$.

3.2.3. Parietal

Theta: The results revealed a significant main effect for test phase, $F(1, 74) = 5.89$, $p = 0.02$, $\eta_p^2 = 0.07$, with a smaller theta power for the before phase (1.60 ± 0.33) than for the after phase (1.67 ± 0.39). Test anxiety had no significant main effect, $F(1, 74) = 0.27$, $p = 0.61$, $\eta_p^2 = 0.004$. No significant interaction effect was found between test phase and test anxiety, $F(1, 74) = 0.001$, $p = 0.98$, $\eta_p^2 < 0.001$.

Beta: The results showed no significant main effect for test phase or test anxiety, $F(1, 74) = 0.36$, $p = 0.55$, $\eta_p^2 = 0.005$, and $F(1, 74) = 2.26$, $p = 0.14$, $\eta_p^2 = 0.03$, respectively. No significant interaction effect was found between test phase and test anxiety, $F(1, 74) = 0.33$, $p = 0.57$, $\eta_p^2 = 0.004$.

TBR: The results revealed a significant main effect for test phase, $F(1, 74) = 10.63$, $p = 0.002$, $\eta_p^2 = 0.126$, with a smaller TBR for the before phase (1.34 ± 0.38) than for the after phase (1.43 ± 0.36). A significant main effect was found for test anxiety, $F(1, 74) = 5.21$, $p = 0.025$, $\eta_p^2 = 0.066$, with a larger TBR for high test anxiety participants (1.48 ± 0.34) than for low test anxiety participants (1.30 ± 0.36). No significant interaction effect was found between test phase and test anxiety, $F(1, 74) = 0.37$, $p = 0.55$, $\eta_p^2 = 0.005$.

4. Discussion

The present study investigated whether TBR is related to test anxiety before and after a 10-minute Raven's intelligence test. Our findings revealed that, TAS score had a significant positive correlation with parietal TBR, but not significant with frontal and central TBR in before test phase. A significantly larger parietal TBR among high test anxiety individuals than among low test anxiety individuals in both test phases. High test anxiety individuals exhibited larger frontal and central TBR than low test anxiety individuals did, but the differences were not significant. The results also showed that both high and low test anxiety individuals had a larger TBR after the test than before the test at the central and parietal sites but not the frontal site. Additionally, no significant difference was found between high and low test anxiety individuals for theta or beta power. Both high and low test anxiety individuals had a larger theta power at all sites after the test than before the test. Individuals had a larger beta power at the frontal site after the test than before the test.

As far as we know, the present study is the first to demonstrate TAS score is significantly positively correlated with TBR, and test anxiety is direct relation with elevated TBR. Cognitive deficits are observable in high test anxiety individuals [30]. Previous studies have shown test anxiety to be significantly and negatively related to a wide range of educational performance outcomes [30]. ACT suggests that test anxiety impairs attentional control of central executive function [16–18]. TBR is considered to be a biomarker for prefrontal cortex (PFC)-mediated attentional control, and we found a relation between test anxiety and elevated TBR, that is, impaired attentional control.

However, Putman et al. suggested that TBR is specific to the frontal but not parietal site [8,31]. In the present study, TAS score is significantly positively correlated with parietal TBR before the test; high test anxiety individuals had significantly larger TBR than low test anxiety individuals at the parietal but not the frontal site. PFC recruitment is considered critical to attentional control [19,32], but the central and parietal regions are also sensitive to the neural activity of attentional control [33]. Additionally, Hua and Zhou found no significant frontal TBR difference between high and low test anxiety individuals ($p = 0.69$) [21]. TBR functioning as an attentional control biomarker may not be specific to the frontal region. We demonstrated that neural activity in the parietal region is sensitive to the cortical–subcortical interactions involved in attentional control.

The present study demonstrated that there is no significant interaction effect between test phase and test anxiety. It indicated that test stress was not required to impair attentional control for high test anxiety individual, which appeared to challenge the definition of test anxiety. A possible explanation for this is that the individuals had already perceived the laboratory environment as a stress-inducing setting, in either the before or after test phase [34]. Thus, high test anxiety individuals had larger parietal TBR than low test anxiety individuals in both test phases. Another possible explanation concerns the 10-minute Raven's intelligence test that the individuals performed to investigate how test anxiety and test stress influence TBR. Some studies have shown that trait anxiety impairs the attentional control in no stress situations [35]. The test anxiety may impair the individual's attentional control

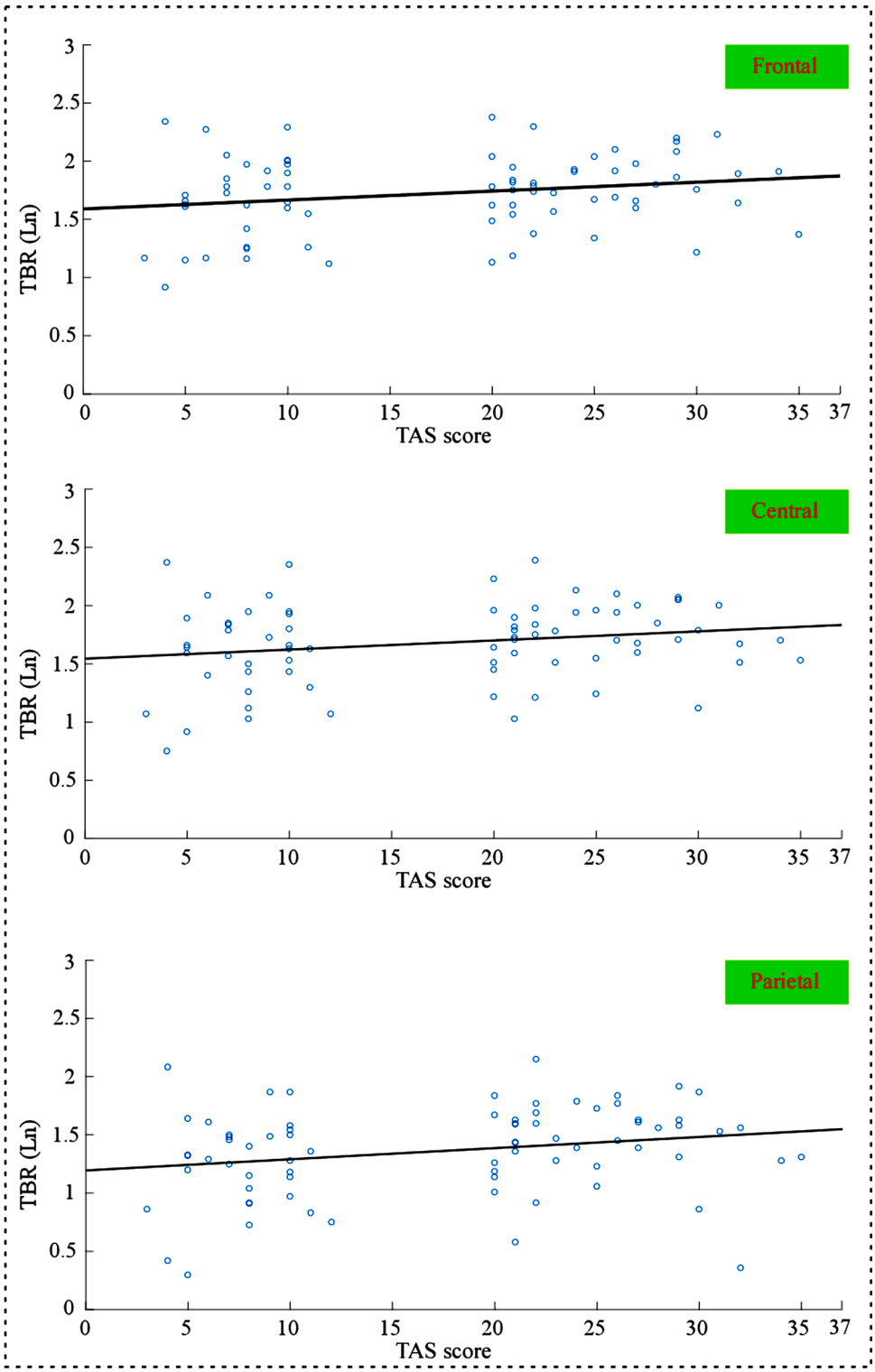

Fig. 1. Scatterplots for the correlations between TAS score and TBR at frontal, central and parietal site, measured before the test. TBR: theta/beta power ratio; TAS: test anxiety scale.

even in a no test stress situation, and this adverse effect will become more obvious in a test stress situation. However, the after test phase in the present study is not equivalent to during test phase. Thus, no significant interaction effect between test phase and test anxiety was found. Future research should examine TBR in students with test anxiety before, during, and after a test.

In summary, TAS score showed a significant positive correlation with parietal TBR before the test; high test anxiety individuals revealed significantly larger parietal TBR than low test anxiety individuals both before and after the test. Therefore, parietal TBR is related to test anxiety and may thus represent a biomarker of potential sensitivity to emotional disorders associated with attentional control deficits.

Credit author statement

Hua Wei, Qiong Huang and Renlai Zhou conceived and designed the

experiments; Qiong Huang performed the experiments; Hua Wei analyzed the data; Hua Wei, Lei Chang and Renlai Zhou wrote the paper.

Declaration of Competing Interest

None.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.neulet.2020.135323.

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