Biological Psychology 193 (2024) 108873

Contents lists available at ScienceDirect

Biological Psychology

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

Effectiveness of acute aerobic exercise in regulating emotions in individuals with test anxiety

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ARTICLE INFO

Keywords:
Test anxiety
Acute exercise
Aerobic exercise
Frontal Alpha Asymmetry (FAA)
Electroencephalography (EEG)

ABSTRACT

High levels of test anxiety can cause negative emotional interference and have adverse effects in multiple aspects. It is currently unclear whether acute aerobic exercise can effectively reduce a series of negative emotions triggered by test anxiety. This study investigates the impact of 30 min of moderate-intensity aerobic exercise on the subjective emotional responses and frontal alpha asymmetry (FAA) in individuals with high test anxiety. Forty-four college students with high test anxiety were randomly assigned to an aerobic exercise group and a control group. Each group underwent two tests, involving subjective scale measurements and resting-state EEG recordings, with a seven-day interval between tests. Results showed that after 30 min of moderate-intensity acute aerobic exercise, the intervention group had significantly reduced scores in subjective negative emotional experiences, and FAA indicators significantly increased. The study suggests that acute aerobic exercise can enhance the emotional regulation ability of college students with high test anxiety and reduce their negative emotions.

1. Introduction

Talent is the most valuable resource in the 21st century. Tests, as the most commonly used means of talent selection worldwide, significantly influence further education, employment, and promotion. Important tests inevitably cause anxiety in some individuals. Test anxiety, as a situational personality trait (Zeidner, 1998), manifests as excessive worry, irrelevant thoughts, psychological confusion, tension, and physiological arousal in evaluative situations. Research has shown that test anxiety is prevalent among students at all school stages, with over 25 % experiencing high levels of test anxiety (Putwain et al., 2011; Saravanan et al., 2014; Huang & Zhou, 2019).

Test anxiety adversely affects students' physiology, cognitive function, academic performance, and mental health. Physiologically, highly test-anxious students may experience palpitations, sweating, dizziness during tests, and in daily life, they may suffer from anorexia, insomnia or hypersomnia, endocrine disorders (Liu, 2012). Test anxiety may lead to a decline in cognitive function, reducing learning and performance efficiency (Putwain et al., 2011). Studies have found significant negative correlations between test anxiety and various learning performances across different school stages (Steinmayr et al., 2016; von der Embse et al., 2018; Zhang & Zhou, 2016). The negative impact of test anxiety increases the likelihood of poor test performance, which in turn exacerbates test anxiety, creating a vicious cycle between anxiety and performance (Dawood et al., 2016; Fincham et al., 1989; Rana & Mahmood, 2010). Over time, this cycle maintains and reinforces the individual's test anxiety, continuously impairing their academic performance. Additionally, long-term test anxiety may lead to a series of mental health problems, such as decreased social adaptability, lack of learning initiative, reduced individual well-being, and in severe cases, depression or anxiety disorders (von der Embse et al., 2018). Academics and educators widely recognize that test anxiety significantly affects students' academic performance and mental health (Chapell et al., 2005; Zeidner, 2007). Therefore, how to effectively alleviate test anxiety has become a research topic of great concern in the field of education.

Common intervention methods for test anxiety include psychological intervention, skill training intervention, and pharmacological intervention. Psychological intervention is currently the most commonly used method (Zeidner, 1998), mainly divided into two categories: one focuses on reducing the emotional arousal of test anxiety using behavioral therapy techniques such as systematic desensitization and biofeedback training; the other aims to improve cognition to alleviate anxiety using cognitive therapy, such as attention training and working memory refreshing training. Skill training interventions usually focus on

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https://doi.org/10.1016/j.biopsycho.2024.108873
Received 19 July 2024; Received in revised form 25 August 2024; Accepted 17 September 2024
Available online 18 September 2024

two aspects (e.g., Dendato & Diener, 1986): effective strategies for learning and encoding learning materials (e.g., deep learning and rote memorization), and effective strategies during the test process (e.g., allocating more time to questions representing a larger proportion of the test score). Pharmacological interventions target the neurochemical sources of anxiety, using sedatives, receptor blockers, antidepressants, selective serotonin reuptake inhibitors (SSRIs), etc., to relieve anxiety. Existing interventions may have side effects or require long waiting times and intervention cycles, as well as professional therapists or specialized equipment and venues, limiting their feasibility. Therefore, finding a more convenient and low-cost intervention method has become a focus in test anxiety intervention. Exercise intervention, a cheap and self-controllable treatment method, has been proven to have many physiological and psychological benefits, and may be an effective intervention.

Exercise, as a potential intervention for mental disorders, has attracted widespread attention in the fields of education and mental health. Exercise intervention refers to improving individuals' physical and mental health status through physical exercise, encompassing various forms of physical training ranging from light aerobic exercise to high-intensity strength training. It is widely recognized as a safe, reliable, and cost-effective intervention that can be applied to many different groups, including students, adults, and the elderly. Acute exercise, such as fast running or high-intensity aerobic exercise, can serve as an immediate intervention to rapidly increase the levels of neurotransmitters in the brain, such as dopamine and endorphins, thereby improving emotional state (Dinas et al., 2011). For negative emotions, acute aerobic exercise helps overcome emotion regulation deficits and accelerates recovery from subsequent stress sources (Bernstein & McNally, 2018). Numerous studies have found that after acute aerobic exercise, participants reported significant reductions in their state anxiety (Cox et al., 2004; Herring et al., 2019; Petruzzello & Landers, 1994; Petruzzello & Tate, 1997).

In terms of the acute intervention effects of exercise on test anxiety, current research findings are somewhat controversial. Doan et al. (1995) measured the effectiveness of aerobic exercise, relaxation training, or a control condition (i.e., magazine reading) in coping with test anxiety. The results showed that both exercise and relaxation reduced test anxiety. Plante et al. (1996) found that both 15-minute aerobic exercise and relaxation therapy (i.e., being in a relaxing music environment) played a role in reducing test anxiety among college students. Although there were differences in the intervention effects, the differences disappeared after exposure to the stressful "IQ test," and the effect size analysis showed that the exercise group experienced less anxiety increase in the subsequent stressful IQ test, indicating that exercise had a better stress prevention effect than the relaxing music and natural scene condition. However, some studies have reported no improvement in test anxiety after acute exercise. Thompson et al. (2016) conducted a 40-minute moderate-intensity physical education intervention for fifth-grade students before the exam and found no significant difference between the intervention group and the control group in the Children's Test Anxiety Scale (CTAS) student survey dimension, but the intervention group had better test performance in the teacher report dimension. Mavilidi et al. (2020) did not find that short-term (10-minute) acute recess physical activity had a direct improvement effect on test anxiety among sixth-grade children. The inconsistency in these research conclusions is influenced by multiple factors, such as the type, duration, and intensity of exercise, which can affect specific intervention effects. A major limitation of most current studies is the lack of rigorous control of exercise intensity, and the measurement of intervention effects, i.e., emotional measurement, relies solely on subjective reports, which may result in experimental results that do not fully reflect individual emotional changes.

Electroencephalography (EEG) is a neurobiological technique that can be used to measure emotions. In contemporary theoretical models, emotions are conceptualized as two primary dimensions: approach and withdrawal (Davidson, 1998; Lang et al., 1998). The approach system is primarily associated with positive emotions, while the withdrawal system is linked to most negative experiences. Davidson proposed that the left frontal cortex is activated during positive affective states, while the right frontal cortex is activated during negative affective states. Frontal alpha asymmetry (FAA) has been widely viewed as a typical biomarker for measuring emotions, measured by collecting EEG activity in the alpha band (8–13 Hz) of the dorsolateral and ventrolateral prefrontal cortex. Alpha waves are an indicator of cortical activity, with their power inversely related to active processing in the cortical system (Oakes et al., 2004). As the frontal lobe or its individual hemisphere becomes more active, alpha waves decrease due to low alpha power (Klimesch, Sauseng, & Hanslmayr, 2007). Therefore, higher relative left-hemisphere activity (i.e., higher FAA) is associated with positive emotions or approach motivation, while higher relative right-hemisphere activity (lower FAA) is associated with negative emotions or avoidance motivation (Davidson, 2004; Harmon-Jones & Gable, 2018).

Studies have shown that left frontal alpha asymmetry in the alpha band is associated with positive psychological responses, such as approach motivation, greater optimism (De Pascalis et al., 2013), reduced sensitivity to negative outcomes (Nash et al., 2012), and adaptive behavior in different environments (Meyer et al., 2015). Higher right frontal alpha asymmetry is often accompanied by greater stress responses (Shields & Moons, 2016), negative biases toward threats (Grimshaw et al., 2014), and increased risk of mental illness. Several studies have found a significant negative correlation between right frontal alpha asymmetry and individual levels of anxiety and depression (Coan & Allen, 2004; Gold et al., 2013), suggesting that frontal alpha asymmetry may be a potential biomarker for measuring anxiety. Furthermore, higher frontal asymmetry scores represent greater leftward asymmetry during cognitive down-regulation processes, indicating better emotional regulation abilities in individuals (Meyer et al., 2015).

According to Davidson's theory and related evidence, exercise can alter emotions, and emotional responses may be related to left frontal asymmetry (Davidson, 2004). Although individual studies have reported no positive effects of 20–30 min of moderate-intensity aerobic exercise on FAA in adults (Lattari et al., 2016; Petruzzello & Tate, 1997), more studies have reported positive effects of moderate-intensity acute aerobic exercise on FAA in healthy young adults (Hicks et al., 2018; Ohmatsu et al., 2014; Woo et al., 2009, 2010), with 30 min of aerobic exercise promoting maximal relative left frontal activation (Woo et al., 2009). A study on healthy participants also showed that regardless of exercise intensity (low, moderate, high), increased relative left frontal activation was observed after exercise (Woo et al., 2010). Reports suggest that changes in frontal alpha asymmetry after exercise are related to changes in state anxiety, with higher relative left hemisphere activity often accompanying reductions in post-exercise anxiety (Petruzzello & Landers, 1994; Petruzzello & Tate, 1997). Therefore, we hope to use FAA as an index of emotional improvement and, combined with subjective reports from previous studies, better assess the intervention effects of acute aerobic exercise on test anxiety individuals' emotional experiences.

Based on the above background, this study aims to explore the intervention effects of a 30-minute acute aerobic exercise intervention on test anxiety in college students preparing for high-stakes exams. During the intervention, real-time heart rate monitoring will be conducted to ensure that the intensity remains moderate. Emotional experiences will be measured using subjective assessment scales combined with frontal alpha asymmetry indicators. We predict that after the acute aerobic exercise intervention, the level of test anxiety in high-test anxiety individuals will decrease, negative emotions will be alleviated, and the degree of frontal alpha asymmetry will increase, indicating greater leftward asymmetry.

2. Materials and methods

2.1. Participants

Participants were recruited through online and offline posters at Nanjing University, comprising full-time undergraduate and graduate students. During recruitment, the assignment to the experimental group was concealed. In accordance with Newman, (1996) research,individuals scoring above 20 on the Test Anxiety Scale (TAS) were selected as high test anxiety individuals (Newman, 1996). Participants were screened to meet the following inclusion criteria: (1) right-handed; (2) normal or corrected-to-normal vision; (3) no psychiatric, neurological, cardiovascular diseases, or physical disabilities that would prevent participation in exercise (i.e., all items on the PAR-Q were answered "no"). Additionally, participants with depressive tendencies (scoring above 14 on the Beck Depression Inventory) (Beck et al., 1996) were excluded to avoid confounding effects of depression on the outcomes related to test anxiety.

Ultimately, 44 high anxiety participants were selected (mean TAS = 27.43), and randomly assigned to the aerobic exercise group and the control group using a computer-generated random number sequence to ensure unbiased allocation. The aerobic exercise group consisted of 22 participants, including 13 females and 9 males, with an average age of 21.27 ± 1.67 years, and an average TAS score of 27.95 ± 2.33. The control group also consisted of 22 participants, including 14 females and 8 males, with an average age of 20.95 ± 1.53 years, and an average TAS score of 26.91 ± 2.05. Detailed descriptive statistics are provided in Table 1.

Participants were instructed to avoid intense exercise and alcohol for 24 h before each session, and to refrain from consuming caffeinated beverages within four hours before the experiment. They were also advised to wear comfortable clothing and shoes during the experiment.

The experiment was conducted in May and June of the same year, a period when students typically face multiple end-of-term course exams and extracurricular tests such as the College English Test (CET) levels 4 and 6, and computer tests. This timeframe was chosen because students are more likely to experience test anxiety due to the upcoming exams.

The necessary sample size was estimated using G-Power 3.1, with the significance level set at $\alpha = 0.05$ and the required statistical power $(1 - \beta) = 0.8$. The calculated minimum sample size required was 34 participants (minimum group sample size of 17). This experiment included 22 samples in both the exercise and control groups, meeting the required sample size for the experimental design.

2.2. Subjective assessment scales

2.2.1. Test Anxiety Scale (TAS)

The Test Anxiety Scale (TAS) (Sarason, 1978) effectively differentiates individuals with varying levels of test anxiety. The scale comprises 37 items that address attitudes towards exams and psychological and physical discomfort experienced before and after exams. In this study, we used the Chinese version (Wang, 2001), which has high internal consistency reliability (Cronbach's alpha = 0.80).

Table 1
Descriptive statistics for all groups (Mean ± SD).

	AE group			C group		
Age	21.27	±	1.67	20.95	±	1.53
N	22			22		
Gender						
Female	13			14		
Male	9			8		
TAS	27.95	±	2.33	26.91	±	2.05

Note: AE group, aerobic exercise group; C group, control group;

2.2.2. Test Anxiety Inventory (TAI)

The Test Anxiety Inventory (TAI) (Spielberger, 2010) assesses the two main components of test anxiety: worry and emotionality. Participants report the extent of their anxiety experiences before, during, and after exams, and the inventory measures individual differences in anxiety tendencies in test situations. The Chinese version (Wang, 2003) has good internal consistency (Cronbach's alpha = 0.80).

2.2.3. Positive and Negative Affect Schedule (PANAS)

The Positive and Negative Affect Schedule (PANAS) (Watson et al., 1988) effectively measures positive and negative emotions. The scale consists of two subscales, each containing 10 items that describe positive affect (Positive Affect) and negative affect (Negative Affect). Participants rate their feelings, reactions, and identification levels using a five-point Likert scale. In the Chinese version (Chen and Zhang, 2004), the Cronbach's alpha coefficients for the positive affect and negative affect subscales are 0.82 and 0.80, respectively.

2.2.4. Profile of Mood States (POMS)

The Profile of Mood States (POMS) (McNair et al., 1971) evaluates and assesses the emotional states of participants. It includes seven subscales: tension, anger, fatigue, depression, confusion, vigor, and self-esteem. Higher scores in the first five subscales indicate more severe negative emotions, while higher scores in the vigor and self-esteem subscales indicate more prominent positive emotions. The total mood disturbance (TMD) score is calculated by summing the scores of the five negative subscales, subtracting the scores of the two positive subscales, and adding a constant. Higher TMD scores indicate more severe negative emotions and greater emotional disturbance. The internal consistency reliability of the Chinese version ranges from 0.77 to 0.92 across the subscales (Li and Ji, 1997).

2.3. Resting-state task

During the resting-state task, participants were instructed to open or close their eyes every minute according to auditory prompts. During the eyes-open phase, participants were required to fixate on a "+" presented at the center of a computer screen. The entire task lasted for 8 min.

2.4. Aerobic exercise

The benefits of exercise, particularly in reducing negative emotions and enhancing emotional regulation, typically exhibit an inverted U-shaped response to exercise intensity (McMorris & Graydon, 2000). For moderate-intensity exercise, a duration of 20–40 min is necessary for these emotional improvements (Chen et al., 2018; Hansen et al., 2001). Therefore, during the second experimental session, participants engaged in 30 min of moderate-intensity acute aerobic exercise. According to the guidelines of the American College of Sports Medicine, moderate intensity is defined as 60–70% of the predicted maximum heart rate (HRmax) and a perceived exertion (RPE) level of 12–14 ("somewhat hard" to "moderate") (Ding et al., 2020). HRmax was calculated using the formula: HRmax = 220 - age (in years).

All exercise interventions were conducted on a treadmill. To ensure control over exercise intensity, participants wore a heart rate monitor (Polar RS800CX; Polar Electro Oy, Kempele, Finland). A 5-minute warm-up was performed first to bring the heart rate to the lower limit of the target heart rate (60% HRmax) within 5 min. Participants then exercised for 25 min within the target heart rate range (60–70%). The perceived exertion level was assessed every 2 min using the RPE scale. If a participant's heart rate or RPE level exceeded the moderate intensity range, the treadmill speed was adjusted accordingly. To minimize confounding effects from social interaction between participants and researchers during exercise, the RPE assessment procedure was explained to all participants before the exercise session. During the exercise session, participants verbally reported their perceived exertion levels using a

copy of the RPE scale.The control group was instructed to engage in a 30-minute seated control activity, during which participants read sports-related magazines and books to avoid boredom or negative emotions from prolonged sitting.

2.5. Experimental procedure

Upon their initial arrival at the laboratory, participants completed demographic surveys and assessments including the TAS, TAI, PANAS, and POMS. Following these assessments, participants performed the resting-state task while their EEG data was recorded.

During the second visit, which occurred one week after the first to avoid direct time-related effects, participants underwent the same assessments and procedures at the same time of day to control for potential circadian rhythm differences. In the second session, participants either engaged in 30 min of aerobic exercise or 30 min of seated reading as a control activity. After a 15-minute rest period to allow their heart rate to return to resting levels, participants completed the TAS, TAI, PANAS, and POMS questionnaires again, performed the resting-state task, and had their EEG data recorded.

2.6. EEG data recording

EEG data was collected using the ESI-64 channel EEG recording and analysis system (Scan 4.5, Neurosoft Labs, Inc.) from Neuroscan. Scalp EEG was recorded through 64 Ag/AgCl electrodes embedded in an electrode cap according to the international 10–20 system. Electrodes placed 1 cm from the outer canthi of both eyes recorded horizontal electrooculograms (HEOG), while electrodes placed 1 cm above and below the left eye recorded vertical electrooculograms (VEOG). The left mastoid served as a reference, and the forehead served as ground. The data was band-pass filtered from 0.05 to 100 Hz and sampled at 1000 Hz, with scalp impedance kept below 10 kΩ.

2.7. EEG data analysis

EEG data were processed using the MATLAB-based open-source toolbox EEGLAB (Delorme & Makeig, 2004). The reference was converted from a unilateral mastoid to a bilateral mastoid reference, and the continuous raw EEG data were segmented into 1-second epochs. After downsampling the data to 500 Hz, a band-pass filter of 2–30 Hz and a notch filter to eliminate 50 Hz power line noise were applied. Independent Component Analysis (ICA) (Delorme et al., 2007) was used to remove artifacts such as eye movements, blinks, and body movements. EEG segments with amplitudes exceeding ± 100 μV were discarded.

Fast Fourier Transform (FFT) was used to obtain the spectral power of the alpha band (8–13 Hz). The spectral power was log-transformed using the natural logarithm, and the alpha values at electrodes F3 and F4 were extracted. Frontal alpha asymmetry (FAA) scores were calculated using two methods: (1) subtracting the log-transformed alpha power of the left frontal region (F3) from the right frontal region (F4) (Ln[F4] - Ln[F3]) to obtain FAA1 (Coan & Allen, 2004); and (2) normalizing the difference by taking the ratio of the difference between right (F4) and left (F3) alpha power levels to their sum, expressed as a percentage: (F4 - F3) / (F4 + F3) * 100% to obtain FAA2 (Davidson, 1988).

It is noteworthy that higher FAA scores during resting state indicate relatively lower alpha power in the left frontal region, reflecting greater activity in the left frontal area, which is associated with more positive emotional responses (Coan & Allen, 2004).

2.8. Statistical analysis

To ensure the comparability of the groups at baseline, independent samples t-tests were first conducted to examine any significant differences between the aerobic exercise (AE) group and the control (C) group in pre-test scores across all main variables.

To examine the effects of acute exercise, repeated measures analysis of variance (ANOVA) was conducted with a 2 (Group: Intervention, Control) × 2 (Time: Pre-test, Post-test) design, comparing differences between the aerobic exercise group and the control group before and after the intervention.

For the subjective assessment scales, repeated measures ANOVA was conducted separately for TAS scores, TAI scores, positive affect (PA) and negative affect (NA) scores from the PANAS, and the seven subscales and total mood disturbance (TMD) score from the POMS. For the analysis of each individual ANOVA, Bonferroni correction was applied to adjust for multiple comparisons within each test. Additionally, to manage the risk of Type I errors across the multiple ANOVAs performed on different scales, we employed False Discovery Rate (FDR) control using the Benjamini-Hochberg (BH) procedure with a desired FDR rate of 0.05.

For the measurement of frontal alpha asymmetry, repeated measures ANOVA was conducted using FAA1 (Ln[F4 alpha] - Ln[F3 alpha]) and FAA2 ((F4 - F3) / (F4 + F3) * 100%) as dependent variables. Multiple comparisons were adjusted using the Bonferroni correction.

In addition to the primary analyses, we conducted a correlation analysis to explore the relationship between the changes in various psychological scale scores and the changes in frontal alpha asymmetry (FAA) indices (FAA1 and FAA2) in the intervention group. Pearson correlation coefficients (r) were calculated to determine the strength and direction of the relationship between the change scores on the Test Anxiety Scale (TAS), Positive and Negative Affect Schedule (PANAS), and other relevant scales, and the changes in FAA1 and FAA2 values pre- and post-intervention. Correlations were considered significant at $p < 0.05$. We interpreted the magnitude of correlations according to established guidelines (Cohen, 1988) as “small” ($r = 0.10$), “medium” ($r = 0.30$), and “large” ($r = 0.50$).

In the "Results" section, data are typically reported as mean ± standard error. The significant effects are reported with partial eta squared effect sizes (η^2_p).

3. Results

3.1. Homogeneous tests for randomization and for main variables in the Pre-test

Results of the independent sample t-tests showed that there were no significant differences between the AE and C groups in any of the pre-test measures (all $p > 0.05$). This suggests that the groups were comparable at baseline, and any subsequent differences observed can be attributed to the intervention rather than initial disparities between the groups.

3.2. Subjective emotional assessment

To evaluate the effects of the intervention on subjective emotional states, we analyzed the scores from the TAS, TAI, PANAS, and POMS questionnaires. The results are presented below.

3.2.1. Test Anxiety Scale (TAS)

We conducted a 2 (Group: Exercise/Control) × 2 (Time: Pre-test/Post-test) repeated measures ANOVA with the TAS scores as the dependent variable. The results, shown in Table 2, indicated a significant interaction between Time and Group, $F(1, 42) = 8.23$, $p = .006$, $\eta^2_p = .164$. Further simple effects analysis revealed that the TAS scores in the exercise group significantly decreased from pre-test to post-test ($p = .007$), while no significant changes were observed in the control group. The main effects of Group, $F(1, 42) = .049$, $p = .826$, and Time, $F(1, 42) = 1.27$, $p = .266$, were not significant.

3.2.2. Test Anxiety Inventory (TAI)

With TAI scores as the dependent variable , a 2 (Group: Exercise/

Table 2
Pre and Post TAS、TAI、PANAS、POMS scores (M ± SE) for all groups.

Scale		AE group (n = 22)						C group (n = 22)						*p*	
		Pre			Post			Pre			Post				
TAS		27.95	±	3.33	26.18	±	5.49	26.91	±	2.04	27.68	±	3.08	0.006	**
TAI		51.68	±	9.07	39.59	±	10.17	48.95	±	4.59	46.82	±	8.09	0.003	**
PANAS															
	PA	28.05		6.62	27.73		6.54	28.00	±	6.99	25.36	±	7.38	0.120	
	NA	20.59	±	6.33	15.73	±	4.88	17.55	±	5.65	19.18	±	6.87	0.000	**
POMS															
	T–A	8.77	±	5.21	5.68	±	4.49	6.77	±	4.23	6.91	±	4.82	0.003	**
	D	5.82	±	5.84	3.64	±	4.04	5.55	±	4.31	6.36	±	3.76	0.010	**
	A–H	5.73	±	5.16	3.32	±	3.80	5.32	±	4.16	5.91	±	5.51	0.007	**
	V	10.41	±	5.23	10.45	±	5.37	9.45	±	4.76	8.64	±	3.86	0.249	
	F	7.73	±	5.12	6.86	±	4.39	7.86	±	4.54	8.23	±	4.16	0.256	
	C	7.95	±	4.46	5.82	±	3.53	6.14	±	3.91	6.55	±	3.33	0.037	*
	S	6.91	±	3.96	6.50	±	3.79	6.05	±	3.15	5.23	±	2.62	0.516	
	TDM	118.68	±	27.14	108.36	±	21.97	116.14	±	20.67	120.09	±	19.83	0.001	**

Note: AE group,aerobic exercise group;C group,control group;PA,positive affect;NA,negative affect;T–A, tension–anxiety; D, depression; A–H, anger–hostility; V, vigor; F, fatigue; C,confusion.;S,self-esteem;TDM,total mood disturbance ; * *p < Adjusted Significance Level;* p > Adjusted Significance Level (but < 0.05, for marginal results).

Control) × 2 (Time: Pre-test/Post-test) repeated measures ANOVA showed significant interaction between Time and Group, $F(1, 42) = 10.236$, $p = .003$, $\eta^2_p = .196$ (see Table 2). Simple effects analysis indicated that the exercise group's TAI scores significantly decreased from pre-test to post-test ($p < .001$), and the post-test TAI scores in the exercise group were significantly lower than those in the control group ($p = .013$). The main effect of Group was not significant, $F(1, 42) = 1.344$, $p = .253$, while the main effect of Time was significant, $F(1, 42) = 20.910$, $p < .001$, $\eta^2_p = .332$, indicating that post-test TAI scores were significantly lower than pre-test scores.

3.2.3. Positive and Negative Affect Schedule (PANAS)

Separate 2 (Group: Exercise/Control) × 2 (Time: Pre-test/Post-test) repeated measures ANOVAs were conducted with the Positive Affect (PA) and Negative Affect (NA) scores from PANAS as dependent variables. For PA, neither the interaction effect nor the main effects of Time and Group were significant ($p > .050$). For NA, there was a significant interaction between Time and Group, $F(1, 42) = 20.42$, $p < .001$, $\eta^2_p = .327$. Simple effects analysis showed that the NA scores in the exercise group significantly decreased from pre-test to post-test ($p < .001$), while no significant changes were observed in the control group. The main effect of Group was not significant, $F(1, 42) = .05$, $p = .902$, but the main effect of Time was significant, $F(1, 42) = 5.04$, $p = .03$, $\eta^2p = .107$, indicating that post-test NA scores were significantly lower than pre-test scores.

3.2.4. Profile of Mood States (POMS)

Separate 2 (Group: Exercise/Control) × 2 (Time: Pre-test/Post-test) repeated measures ANOVAs were conducted for each POMS subscale and the Total Mood Disturbance (TMD) score. None of the subscales showed a significant main effect of Group (*ps* >.284).

Tension-Anxiety (T-A): Significant interaction between Time and Group, $F(1, 42) = 9.77$, $p = .003$, $\eta^2_p = .189$. Simple effects analysis revealed a significant decrease in T-A scores from pre-test to post-test in the exercise group ($p < .001$), but not in the control group. The main effect of Time was significant, $F(1, 42) = 8.19$, $p = .007$, $\eta^2_p = .153$. Depression-Dejection (D): Significant interaction between Time and Group, $F(1, 42) = 7.31$, $p = .01$, $\eta^2_p = .148$. Simple effects analysis showed a significant decrease in D scores from pre-test to post-test in the exercise group ($p = .008$), and the post-test D scores in the exercise group were significantly lower than those in the control group ($p = .025$). The main effect of Time was not significant ($p = .226$). Anger-Hostility (A): Significant interaction between Time and Group, $F(1, 42) = 7.96$, $p = .007$, $\eta^2_p = .159$. Simple effects analysis revealed a significant decrease in A scores from pre-test to post-test in the exercise group ($p = .008$), and the post-test A scores in the exercise group were significantly lower than those in the control group ($p = .003$). The main effect of Time was not significant ($p = .095$). Vigor-Activity (V): Neither the main effect of Time ($p = .302$) nor the interaction effect was significant ($p = .249$). Fatigue-Inertia (F): Neither the main effect of Time ($p = .641$) nor the interaction effect was significant ($p = .256$). Confusion-Bewilderment (C): Significant main effect of Time, $F(1, 42) = 4.66$, $p = .037$, $\eta^2_p = .100$, and a significant interaction between Time and Group, $F(1, 42) = 10.12$, $p = .003$, $\eta^2p = .194$. Simple effects analysis showed a significant decrease in C scores from pre-test to post-test in the exercise group ($p < .001$). Self-Esteem (S): Neither the main effect of Time nor the interaction effect was significant (*ps* >.056). Total Mood Disturbance (TMD): The main effect of Time was not significant ($p = .129$), but there was a significant interaction between Time and Group, $F(1, 42) = 10.09$, $p = .001$, $\eta^2_p = .223$. Simple effects analysis revealed a significant decrease in TMD scores from pre-test to post-test in the exercise group ($p = .001$).

Compared to the control group, which showed no significant differences between pre-test and post-test scores across all subscales, the aerobic exercise group demonstrated significant reductions in scores for all negative emotion subscales (including Tension-Anxiety, Confusion-Bewilderment, Anger-Hostility, and Depression-Dejection) and in the overall TMD score after the intervention.

3.3. Asymmetry of Alpha Power in the Frontal Cortex

To evaluate the effects of the intervention on FAA, we analyzed the FAA1 and FAA2 scores. The results are presented in Table 3.

3.3.1. FAA1 (Ln[F4]–Ln[F3])

A repeated measures ANOVA with a 2 (Group: Exercise, Control) × 2 (Time: Pre-test, Post-test) design was conducted to analyze the asymmetry of alpha power (FAA1). The results are illustrated in Fig. 1. There was a significant interaction between Time and Group, $F(1, 42) = 11.03$, $p = .002$, $\eta^2_p = .208$. Simple effects analysis revealed that post-test FAA1 scores were significantly higher than pre-test scores in the exercise group ($p < .001$), and post-test FAA1 scores in the exercise group were significantly higher than those in the control group ($p = .001$).

3.3.2. FAA2 ((F4–F3)/(F4+F3) * 100%)

We conduct a 2 (Group: Exercise/Control) × 2 (Time: Pre-test/Post-test) repeated measures ANOVA the normalized asymmetry of alpha power (FAA2). The results are shown in Fig. 2. There was a significant interaction between Time and Group, $F(1, 42) = 20.583$, $p < .001$, $\eta^2_p = .329$. Simple effects analysis indicated that post-test FAA2 scores were

Table 3
FAA Indicators (M ± SE) for All Groups Pre- and Post-Intervention.

Results	AE group (n = 22)						C group (n = 22)					
	Pre			Post			Pre			Post		
FAA1	−0.115	±	0.059	0.065	±	0.137	−0.123	±	0.082	−0.079	±	0.132
FAA2	−5.75	±	2.94	3.21	±	6.76	−6.13	±	4.05	−5.88	±	5.03

Note: AE group,aerobic exercise group;C group,control group;

Table 4
Correlation between changes in scale scores and changes in FAA1 and FAA2 in the AE Group.

	FAA1	FAA2
TAS	−.211	−.055
TAI	−.100	.250
PANAS		
PA	−.026	.009
NA	−.437*	−.493*
POMS		
T–A	−.295	−.287
D	−.252	−.322
A–H	−.399	−0.425
V	−.201	−.285
F	.305	.393
C	−.075	−.123
S	.264	.177
TDM	−.359	−.406

Note: AE group,aerobic exercise group;* $p < 0.05$

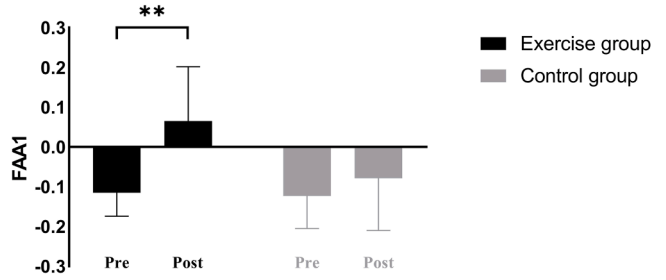

Fig. 1. FAA1 Scores Pre and Post-Intervention for Exercise and Control Groups. * $p < .05$, * * $p < .01$.

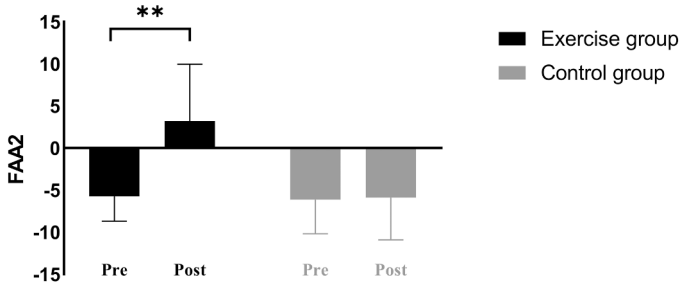

Fig. 2. FAA2 scores pre and post-intervention for exercise and control groups. * $p < .05$, * * $p < .01$.

significantly higher than pre-test scores in the exercise group ($p < .001$), and post-test FAA2 scores in the exercise group were significantly higher than those in the control group ($p < .001$).

3.4. Correlation of EEG measures and psychiatric tests

The correlation analysis revealed that the changes in the Negative Affect dimension of the PANAS scale (PANAS-NA) exhibited significant negative correlations with both FAA1 and FAA2 indices ($ps < 0.05$). This indicates a moderate to high negative relationship, suggesting that as negative affect scores decreased post-intervention, the FAA1 and FAA2 values also tended to decrease. No significant correlations were found between the changes in other psychological scale scores and FAA indices. These findings might reflect an improvement in emotional regulation following the aerobic exercise intervention.

4. Discussion

In our study, we examined whether 30 min of moderate-intensity acute aerobic exercise could reduce test anxiety (TA) and promote frontal alpha asymmetry. The results indicated that acute moderate-intensity aerobic exercise intervention led to an improvement in mood. Specifically, compared to the control group, individuals who underwent 30 min of moderate-intensity acute aerobic exercise exhibited significantly reduced levels of test anxiety and lower ratings of various negative emotions, except for fatigue. Moreover, this improvement was also reflected at the neurophysiological level. Following the 30-minute acute aerobic exercise intervention, individuals showed increased frontal alpha asymmetry, indicating relatively greater left frontal activation.

After the exercise intervention, individuals with high test anxiety (HTA) showed a decrease in multiple negative emotion ratings. Specifically, the exercise intervention led to a significant reduction in test anxiety, as well as a decrease in negative affect scores on the PANAS scale. On the POMS scale, HTA individuals also exhibited reductions in several negative dimensions (Tension-Anxiety, Depression-Dejection, Confusion-Bewilderment, and Anger-Hostility), along with a decrease in total mood disturbance. This reduction in negative emotion dimensions following exercise intervention aligns with previous research findings (Fumoto et al., 2010; Moraes et al., 2011; Oda et al., 1999; Ohmatsu et al., 2014). However, unlike previous studies that reported decreases only in specific negative dimensions, our study found that the reduction in negative emotions after exercise extended to multiple dimensions of negative emotions on POMS. Previous studies did not specifically screen their participants, leading to potential floor effects in negative emotion scores that could obscure the detection of exercise-induced reductions in negative emotions (Woo et al., 2009, 2010). In contrast, our study focused on individuals with high test anxiety, who likely had higher baseline scores on various negative emotion dimensions, allowing for greater potential for reduction.

Analysis of resting-state EEG after the exercise intervention revealed greater frontal alpha asymmetry (FAA). Both left and right frontal alpha power increased, but the increase in right alpha power was more pronounced.This indicates that individuals with high test anxiety exhibited lower right frontal activation after exercise. Previous studies by Hicks et al. found that aerobic exercise of certain intensity levels led to increases in bilateral frontal alpha power at various post-exercise time points, resulting in relatively greater left frontal activation (Fumoto et al., 2010; Hicks et al., 2018; Moraes et al., 2011; Oda et al., 1999). Specifically, the increase in alpha power at the right F4 site was significantly greater than that at the left F3 site. Our findings are consistent with these results and can be explained by previous theories. According to Davidson (1988), activation of the right frontal cortex is associated with the withdrawal system, where lower right frontal activation predicts lower levels of negative emotions. Therefore, the observed decreases in subjective reports of test anxiety, tension,

depression, and other negative emotional states in individuals with high test anxiety after exercise can be attributed to this neurophysiological change.

The correlation analysis of changes in scale scores and FAA values in the intervention group revealed a significant negative correlation between the changes in FAA and the alterations in the PANAS negative affect dimension. Improvement in Frontal Alpha Asymmetry (FAA) towards left lateralization following exercise may indicate enhanced emotional regulation abilities in individuals (Meyer et al., 2015). Emotional regulation involves consciously managing and altering one's emotions and is closely related to mental health. Previous studies have demonstrated a significant negative correlation between test anxiety levels and emotional regulation (Liu et al., 2021; Shahidi et al., 2017). Individuals with high test anxiety often struggle to actively and effectively regulate their negative emotions in evaluative situations, leading to a cascade of negative emotional experiences and accompanying behavioral reactions. Prior research has found that individuals exhibiting rightward FAA at rest may face difficulties in regulating negative emotions (Davidson, 1998; Kline et al., 2007). Our study results indicated that individuals with high test anxiety demonstrated a pronounced rightward FAA at baseline, indirectly suggesting inherent difficulties in emotional regulation among this population. Therefore, the improvement in FAA following acute aerobic exercise intervention in individuals with high test anxiety may partially enhance their emotional regulation abilities, thereby reducing their levels of test anxiety. However, it is important to note that FAA is not a definitive marker of improved emotional regulation, and it alone does not confirm this improvement. Further investigation is needed, including the use of additional emotional regulation indicators such as the Emotion Regulation Questionnaire (ERQ), heart rate variability (HRV), and other physiological or behavioral measures. This will help clarify the specific effects and mechanisms of acute aerobic exercise on emotional regulation in individuals with high test anxiety.

The improvement in FAA in individuals with high test anxiety following exercise suggests that FAA could be considered as a potential measure of treatment efficacy for test anxiety. However, whether FAA can serve as a biological marker or predictive indicator of test anxiety may still require further research for validation. Our study findings revealed a significant rightward FAA at baseline in individuals with high test anxiety, whereas previous research by Wei and Zhou (Wei & Zhou, 2020) did not find significant differences in resting-state FAA between high and low test anxiety groups but observed significantly higher alpha1 (8–10 Hz) and alpha2 (10–12 Hz) energies in the high test anxiety group. Moreover, our correlation results further indicated that although the changes in FAA after the intervention were negatively correlated with changes in TAS or TAI scores, these correlations did not reach statistical significance. Considering that test anxiety, compared to some other anxiety disorders, is a non-clinical anxiety disorder, factors such as participant age and gender may be important biological moderators. Additionally, methodological factors related to EEG recording, such as time of day and the specific brain regions or sites assessed, may also contribute to differences in research findings. Brière et al. (2003) reported daytime and gender lateralization effects, and FAA is also influenced by daytime and season (Harmon-Jones & Peterson, 2009), with relatively greater right frontal asymmetry reported in early autumn mornings. Therefore, whether FAA can only serve as an outcome variable or can be used as a predictor requires further research investigation.

It is noteworthy that we did not find an increase in subjective reports of positive emotions following exercise. Many previous studies have found significant increases in energy dimensions post-acute exercise intervention (Moraes et al., 2011; Oda et al., 1999; Ohmatsu et al., 2014; Woo et al., 2009, 2010), whereas our study did not. Possible reasons may include our intensity control using the absolute intensity method, where 60–70% of the maximum heart rate was used as the monitoring criterion based on the most commonly used HRmax= 220–age formula. However, recent studies have suggested that HRmax= 207–0.7 *age may be more appropriate for the general population (Gellish et al., 2007), which could lead to signs of overestimation in our maximum heart rate measurement, potentially resulting in higher exercise intensity compared to using maximum oxygen uptake VO2max as a control indicator. Additionally, in our exercise intervention protocol, after a 5-minute warm-up, participants engaged in 25 min of moderate-intensity treadmill exercise, unlike some previous studies that included 5 min of low-intensity recovery cool-down exercise after 15–20 min of exercise. The intensity of exercise under our experimental control, followed by 15 min of rest, may not have fully relieved physical fatigue due to individual differences in lactate metabolism, resulting in no self-reported improvement in energy dimensions. However, it is important to note that VO2 measurement itself requires specialized expensive equipment, which may exceed the requirements of some laboratories. Therefore, in situations where exercise intensity is controlled using heart rate monitoring, subsequent research may consider using relative heart rate calculation methods, such as using heart rate reserve (HRR=HRmax–Hrrest), and exercise intensity measured using target heart rate (THR=(HRmax–HR rest)× %+HR rest).

This study also has certain limitations in the selection of participant samples, as it chose a relatively easy-to-access group of university students as the study population. However, previous research by Huang et al. found that compared to university students, the proportion of test anxiety among middle and high school students in China is significantly higher (Huang & Zhou, 2019). Selecting a more readily available group of university students as the study population may reduce the ecological validity of the exercise intervention's effectiveness in reducing test anxiety. Therefore, future research should consider extending the therapeutic effects of exercise on test anxiety to students in middle school.

One limitation of this study is the absence of a control group comprising individuals with low or moderate test anxiety. This limitation may affect the generalizability of the findings to the broader population, as the results primarily reflect the effects of the interventions on participants with higher levels of test anxiety. Future research should consider including a control group with varying levels of test anxiety to enhance the applicability of the findings.

In the measurement of anxiety, our study results were based on measuring Frontal Alpha Asymmetry (FAA) using resting-state electroencephalography (EEG). Subsequent experiments measuring midline frontal theta (FMθ) during specific tasks, such as those involving effort or attention, may be worthwhile. FMθ is considered a potential biomarker for anxiety (Suetsugi et al., 2000), representing enhanced mental effort and sustained attention observable during low-level conscious states, which may help distinguish between high and low anxiety in pleasant/unpleasant tasks (Mitchell et al., 2008). However, the literature on FMθ is much more limited compared to FAA. It is typically examined in the context of task-related EEG activity but is also evident during rest or even sleep (Inanaga, 1998). Although the literature on FMθ is relatively limited, it can be hypothesized that low levels of FMθ are associated with high levels of anxiety, suggesting that FMθ could serve as another measure of the therapeutic effects of high-level test anxiety.

Based on the above analysis, this study indicates that 30 min of moderate-intensity aerobic exercise can reduce test anxiety and other negative emotional subjective experiences in individuals with high test anxiety, decrease activation in the right frontal brain region, and have a positive effect on the emotional state of individuals with test anxiety.

CRediT authorship contribution statement

Renlai Zhou: Writing – review & editing, Supervision, Project administration, Investigation, Funding acquisition, Conceptualization. **Lingfeng Wu:** Writing – review & editing, Writing – original draft, Visualization, Validation, Resources, Methodology, Formal analysis, Data curation, Conceptualization.

Declaration of Generative AI and AI-assisted technologies in the writing process

All content in this paper was independently produced by the authors without the use of any generative AI or AI-assisted technologies. The design, data collection, analysis, and writing of this research were conducted solely by the authors to ensure the accuracy and reliability of the findings.

Declaration of Competing Interest

None.

Data Availability

Data will be made available on request.

Acknowledgments

This study was supported by National Natural Science of China (Grant No. 32471094) and Science and Technology Innovation 2030 - Major Project of Brain Science and Brain-Like Research Program (Grant No. 2021ZD0200534). We would like to express our gratitude for the support of these projects.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.biopsycho.2024.108873.

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