scientific reports

Check for updates

OPEN

The mediating role of behavioral systems in linking physical activity and anxiety symptoms in college students

Wenli Wang & Hairong Liu✉

Data show that the detection rate of anxiety symptoms among college students has risen from 16.6 to 34.8% over the past 10 years, and that college students are gradually becoming a high prevalence group for anxiety symptoms.This study aims to investigate the relationship between physical activity, behavioral inhibition and activation, and anxiety symptoms in college students. Specifically, it seeks to identify the mediating role of individual subcomponents of behavioral inhibition and activation in the association between physical activity and anxiety symptoms. A total of 5125 college students were recruited to participate in the study. Participants completed the Physical Activity Rating Scale-3, the Behavioral Inhibition/Activation System Scale, and the Generalized Anxiety Disorder-7 (GAD-7) scale. ANOVA, linear regression analysis and structural equation modelling were used to analyse the data and subcomponents of each variable (physical activity, anxiety symptoms, BIS/BAS) were analysed. Anxious college students demonstrated significantly lower scores in reward responsiveness, drive, and fun seeking, while exhibiting higher scores in behavioral inhibition. Additionally, these students engaged in physical activity at lower intensities, for shorter times, with reduced frequency, and overall less total exercise (all $p < 0.001$). Furthermore, a significant negative correlation was observed between levels of physical activity and anxiety ($r = -0.145$, $p < 0.001$), while a weak correlation was identified between physical activity levels and the behavioral inhibition system ($r = -0.020$, $p = 0.156$). Conversely, physical activity levels were significantly positively correlated with the behavioral activation subcomponents of reward responsiveness ($r = 0.062$, $p < 0.001$), drive ($r = 0.122$, $p < 0.001$), and fun seeking ($r = 0.067$, $p < 0.001$). Physical activity, behavioral inhibition, and behavioral activation were significant predictors of anxiety symptoms among university students. Among male students, exercise intensity (Beta= − 0.088, $p = 0.001$) and reward responsiveness (Beta= − 0.255, $p < 0.001$) showed the strongest correlations with anxiety levels, while among female students, exercise time (Beta = − 0.084, $p < 0.001$) and behavioral inhibition (Beta = 0.291, $p < 0.001$) were the most highly correlated. Physical activity levels had a direct effect of 84.37% on reducing anxiety symptoms (Beta= − 0.286, $p < 0.001$), with 15.63% of the effect mediated by the behavioral inhibition and activation system (Beta= − 0.053, $p < 0.001$). The mediating effects of the behavioral inhibition and activation system were stronger in females (29.92%, Beta= − 0.076, $p = 0.001$) compared to males (15.76%, Beta= − 0.061, $p < 0.001$). Factor loadings indicated that exercise time (male: 1.81, female: 2.71) and drive (male: 1.01, female: 1.04) were more effective in alleviating anxiety symptoms, particularly in the dimensions of uncontrollable worrying (1.07), worry too much (1.03), trouble relaxing (1.00), and nervousness (1.00). Physical activity exerts a direct influence on anxiety, with its anxiolytic effects partially mediated by the behavioral inhibition and activation system. This mediating effect is most pronounced in the female college student population.

Keywords Anxiety symptoms, Behavioural Inhibition and activation, College students, Mediating role, Physical activity

Anxiety is an emotional state[1] characterised by excessive and persistent worry with no clear direction to the worry[2]. Common symptoms also include irritability, somatic tension, and insomnia[3]. Anxiety is one of the most common psychological problems among college students, and studies have shown that the detection rate

Faculty for Physical Education, Shanghai International Studies University, Shanghai 201620, China. ✉email:

of anxiety symptoms among college students has risen from 16.6 to 34.8% over the past 10 years[4], and has shown an increasing trend in recent years[5]. The detection rate of anxiety among Chinese college students was 24.9%[6]. Personal emotional balance is challenged in the face of gradually increasing academic pressure[7]. College students are gradually becoming a high prevalence of anxiety, and there is an urgent need to explore effective ways to alleviate anxiety in order to protect their normal life, learning and personality development.

Anxiety symptoms are modulated by a variety of neurobiological systems, in which the behavioural activation system (BAS) and the behavioral inhibition system (BIS) play key roles[8]. the BAS is sensitive to rewarding, non-punishing, and punishment-avoiding stimuli, as convergence to incentive signals, which is responsible for positive emotional experiences. The BIS is sensitive to punishment, non-rewarding, and novelty stimuli and manifests itself as withdrawal to avoidance of error signals. It as a behavioral inhibition system of the individual's behavioral responses, and is responsible for negative emotional experiences[9,10]. Thus, abnormal sensitivity to BIS and BAS can lead to behavioural and psychopathological problems in humans, anxiety being one of them[11]. BIS was found to be a stable predictor of anxiety risk[12], while BAS sensitivity negatively predicted anxiety to a lesser extent[13]. Previous studies have shown that personality traits (BIS and BAS) explained all of the genetic variance in depressive and anxiety symptoms[14]. In terms of neuroanatomical features, it has been shown that females displayed a negative correlation between BIS sensitivity and regional gray matter volume (rGMV) in the parahippocampal gyrus, as well as positive correlations between BAS sensitivity and rGMV in the ventromedial prefrontal cortex and inferior parietal lobule, whereas males showed the opposite pattern. These findings suggest that the brain regions associated with processing of negative emotions and reward-related information may contribute to sex-related differences in rGMV correlates of BIS and BAS, respectively[15].

Physical activity can improve the behavioural activation system and anxiety symptoms[16], and has the advantages of high compliance, low side effects and stable effects[17,18]. The underlying mechanism may be that physical activity increases cerebral blood perfusion[19], upregulates neurotrophic factor levels[20,21], improves the function of the hypothalamic-pituitary-adrenal axis[22], and inhibits the secretion of proinflammatory cytokines[23], which effectively stimulates the central nervous system, improves the BIS/BAS system[24], and improves the ability of emotional homeostasis[7], which in turn alleviates negative emotions, such as anxiety[24,25].Evidence shows that moderate to high intensity physical activity is positively associated with BAS[26], and low intensity physical activity is positively associated with BIS[27]. And people with high BAS are more actively driven to participate in physical activity and have more enjoyable emotional responses to exercise[28]. Regular exercisers have better self-control, which can increase relative left frontal cortex activity, especially at moderate intensities, and contribute to individual BAS[29]. On the other hand, exercise reduces individual BIS by improving individual cardiovascular capacity and tolerance, especially moderate and high intensity exercise[30].

Previous studies have clarified the strong relationship between exercise and anxiety symptoms[31], and it is also clear that exercise enhances the behavioural inhibition system[30], and that the behavioral inhibition and activation system is an influence on anxiety symptoms[13]. However, previous researchers have not verified the existence of the action path of the behavioural inhibition and activation system mediating the involvement of exercise in anxiety symptoms in the college student population, not to mention clarifying which of the four sub-dimensions of reward responsiveness, drive, fun seeking and behavioural inhibition mediate the action path, and the effect of the action needs to be further clarified. Based on the foundation of previous studies and research gaps, the present study proposed the following three hypotheses: (a) There are differences in physical activity, behavioural inhibition system and activation system among college students with different anxiety symptom scores. (b) Physical activity of college students is significantly negatively correlated with anxiety and behavioural inhibition system, and significantly positively correlated with behavioural activation-reward responsiveness, drive, and fun seeking. (c) Physical activity, behavioural inhibition and activation were all predictive of anxiety symptoms in college students, and behavioural inhibition and activation mediated the effect between physical activity and anxiety.

The present study intends to adopt a cross-sectional design to test the research hypotheses and use structural equation modelling to explore the role of behavioral inhibition and activation systems of college students in mediating exercise participation and anxiety symptoms. It will provide a reference for university workers and researchers to promote the physical and mental health of university students.

Subjects and methodology

Participants

Participants in this study were current university students, and all participants volunteered to take the test and signed an informed consent form. The informed consent was obtained from all participants and/or their legal guardians. The study was approved by the university ethics committee (SISUGJ2024015), see the attachment for details. The research have been performed in accordance with the Declaration of Helsinki. We confirm that all research was performed in accordance with relevant guidelines/regulations.

The inclusion and exclusion criteria were as follows: (1) aged 18–24 years old; (2) right-handedness; (3) no history of psychiatric illness and no use of psychotropic medication; (4) no chronic physical illness, no external brain damage, and no visual abnormalities.

Sample size calculation and sampling process: College students were recruited from seven colleges and universities in Songjiang University City, Shanghai, using class-based random cluster sampling. The sample size was calculated according to the following formula: " $n \geq \mu_{\alpha/2} * p * (1\text{-}p) / \delta^2 * deff$ "[32], where the test level α was set at 0.05, the sampling tolerance δ was set at 0.03, and the correction factor for cluster sampling was set at 3. The previous data showed that the detection rate of anxiety symptoms among male university students was p 24.215%, and the detection rate of anxiety symptoms in female college students p is 25.146%[6]. The final calculation is that the sample size of male college students needs 2350 people, and the sample size of female college students needs 2411 people, totalling 4761 people. Based on the actual situation, assuming a balanced ratio of men and women

in the college student population in Songjiang University City, and assuming a 5% sample attrition rate, 5011 college students were planned to be recruited. Sampling was done on a class basis, and a total of 125 classes were selected to participate in the study. A total of 5125 college students volunteered to participate in this study through the preaching and recruitment by teachers and researchers, to whom questionnaires were distributed. The sample of this study is regionally representative and can reflect the physical and mental health status of college students in Shanghai to a greater extent.

Questionnaire survey process and quality control:

(1) Before the test: the researchers were centrally trained to ensure that each person was familiar with the inclusion and exclusion criteria of the research subjects, only those who met the inclusion criteria and did not meet the exclusion criteria were included, and the research subjects were given the number according to the order of inclusion; the researchers grasped the standardised operation methods of each screening scale, and retained all the real data in a timely manner. Before the participants filled in the form, the researchers read out the instructions, explained the entries, clarified that the data obtained were only used for scientific research, emphasised the truthfulness, independence and voluntary responses, and informed the participants of their right to withdraw halfway through the test.
(2) During the test: The researcher prompted the participants to answer the questions as required.
(3) After the test: The researchers checked the missing items and those that were against common sense, and ensured that the information was complete, accurate and truthful by means of filling in and re-filling. All samples containing missing values were excluded. Questionnaires with a filling time shorter than 3 min, questionnaires with regular responses and questionnaires that do not meet the inclusion and exclusion criteria are eliminated to ensure the effective response rate.

The specific process is shown in Fig. 1.

Test instruments

General information questionnaire

It includes the basic information situation of the study subjects such as age, gender, height, weight, grade, smoking and drinking habits, household location, family status and interpersonal relationship.

Physical activity rating scale-3 (PARS-3)

The PARS-3 is suitable for the Physical Activity Survey of Chinese Youth Groups[33] and has good reliability and validity[34]. The scale mainly investigates physical activity in the last month, and it includes intensity, duration, frequency and volume. Where physical activity was graded by intensity, duration and frequency. The scoring scale was as follows: intensity and frequency of exercise were divided into 5 grades ranging from 1 to 5. Exercise duration is also divided into 5 grades, 0–4 points. Exercise = intensity * duration * frequency. Low-intensity physical activity 19 points and below (including 19 points), moderate-intensity physical activity 20–42 points, and high-intensity physical activity 43 points and above (including 43 points); the maximum total score is not more than 100 points, and the minimum total score is not less than 0 points. The Cronbach's α coefficient for this questionnaire was 0.85[33]. The questionnaire has good reliability.

Behavioral inhibition/activation system scale (BIS/ BAS)

The Behavioural Inhibition/Activation System Scale (BIS/ BAS) was developed by Carver and White in 1994[35], and was revised by Li Yanzhang et al.[36] in China into four levels, including behavioral inhibition and behavioural activation (reward responsiveness, drive, and fun seeking) dimensions, with a total of 18 question items. The Likert 4-point scale was used, with each item ranging from 1 to 4 on a scale from "Completely disagree" to "Completely agree". This questionnaire has good reliability[36], the Cronbach's α coefficient for this scale in this study was 0.912, KMO = 0.937.

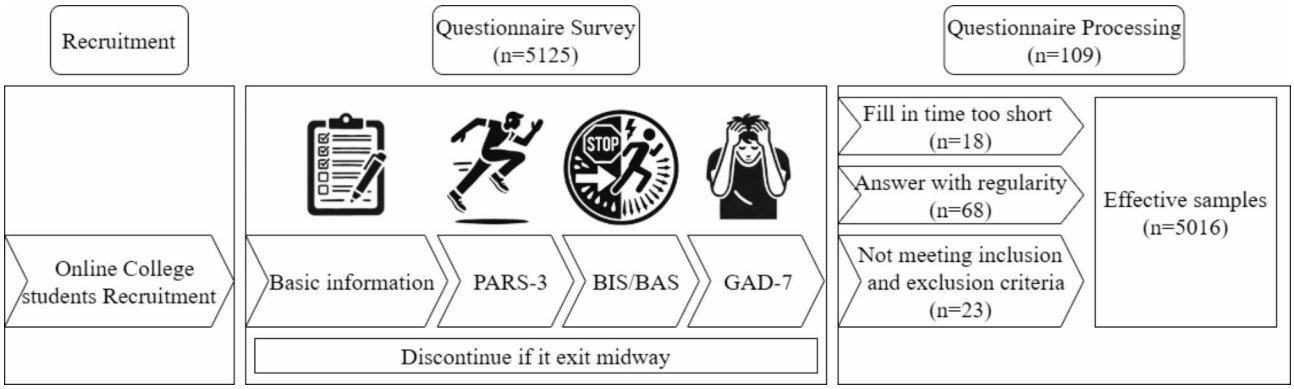

Fig. 1. Flowchart of the test process with the inclusion and exclusion process.

Generalized anxiety disorder 7 item scale (GAD-7)
Anxiety symptoms were assessed using the Generalised Anxiety Disorder 7 Item Scale (GAD-7), which describes the most important diagnostic criteria for generalised anxiety disorder in the DSM-IV-TR. It is the most widely used measure of anxiety in clinical practice and research[37,38], and national and international studies have shown the GAD-7 to have high reliability and validity for anxiety screening[39,42].The GAD-7 asks people how often they have experienced the seven core symptoms of GAD in the past two weeks, with response options of "Not at all", "Several days", "Over half the days" and "Nearly everyday" (on a scale of 0–3). The seven core symptoms include nervousness (GAD1), uncontrollable worrying (GAD2), worry too much (GAD3), trouble relaxing (GAD4), restlessness (GAD5), irritability (GAD6), feeling afraid (GAD7). The total score is the main statistical indicator, the higher the score, the more severe the anxiety. A total score of 0–4 is classified as no anxiety or no clinically significant anxiety: 5–9 is classified as mild anxiety; 10–14 is classified as moderate anxiety; 15–21 is classified as severe anxiety. This questionnaire has good reliability[37], the Cronbach's α coefficient for this scale in this study was 0.940, KMO = 0.935.

Quality control

(1) Quality control of research personnel

The researchers were centrally trained to ensure that each of them was familiar with the inclusion and exclusion criteria of the study subjects, mastered the standardised operation methods of the various screening scales, and retained all authentic data in a timely manner.

(2) Quality control of subject enrolment

The researchers screened the subjects strictly according to the inclusion exclusion criteria. Only those who met the inclusion criteria and did not meet the exclusion criteria were included.

(3) Quality control of questionnaire completion

The questionnaire in the recruitment of this study used electronic questionnaires throughout, and it took about 15 min to complete the whole content. All questions were mandatory, so as to avoid students' omission. The raw data exported from the e-questionnaire platform were checked and cleaned by the researchers to eliminate invalid questionnaires and ensure the effective response rate.

Data analysis
Measurement data were expressed as mean ± standard deviation, and the results were retained with 3 decimals. T-test, one-way ANOVA and LSD post hoc multiple test were used for comparison between groups; count data were expressed as n (%), and chi-square analysis was used for comparison. Pearson correlation analysis and linear regression analysis were used to explore the relationship between physical activity level, executive function, and anxiety; Harman's one-way test was used to test the effect of common method bias, and structural equation modelling was established to examine the role of each subcomponent of executive function in the relationship between physical activity level and anxiety (all the variables were standardised prior to modelling), and the model evaluation indexes were chosen as RMR (root mean square residual), RMSEA (root mean square error of approximation), GFI (goodness of fit index), NFI (normed fit), and NFI (normed fit index), CFI (comparative fit index)[43]. Path analysis parameters were estimated using a non-parametric percentage bootstrap method (without strict requirements on the distribution of the variables), with the number of samples set at 5000, and the mediation effect was defined as statistically significant by the Bias-Corrected 95% Confidence Interval (Bias-Corrected 95% CI) of the mediated path product not crossing 0, with the Percentile 95% CI as a secondary indicator. All statistical inferences were made using two-tailed tests with the test level α set at 0.05. T-tests, one-way ANOVA, LSD post-hoc multiple testing, chi-square analysis, Pearson correlation analysis, Harman one-way test, and multiple linear regression analyses were performed using SPSS Statistics 29.0, and structural equation modelling, path analysis and testing were performed using Amos 23.0.

Results
Differences in demographic characteristics and physical activity, behavioural inhibition and activation systems among university students with different anxiety symptom scores
As shown in Table 1, the age of the subjects was (19.410 ± 1.261) years, BMI was (22.004 ± 4.113) kg/m^2, 47.33% were male, 21.77% were in the habit of drinking alcohol, 5.92% were in the habit of smoking, and 9.25% were in the single parent family. The population was divided into two groups and the scores of non-anxious and anxious population were 0.95 ± 1.367 and 7.82 ± 2.962 respectively. Between-group comparisons by independent t-tests and chi-square tests revealed that there were no significant differences between the non-anxious and anxious populations in terms of BMI, smoking, and single parenthood (all $p > 0.05$); there were differences in age and whether or not alcohol was consumed between the two groups; and there was a significant difference in gender between the groups ($p < 0.001$), which provided a basis for subsequent grouping. In addition, 4.29% of college students had poor family status, 17.24% had difficulties with coursework, and 15.65% never participated in social activities. Family status, coursework pressure, social activities and anxiety symptoms were all significantly associated (all $p < 0.001$), suggesting that this group of people is susceptible to anxiety symptoms.

As shown in Table 2, the anxiety group had lower scores in reward responsiveness, drive, and fun seeking; higher scores in behavioural inhibition; and lower intensity, shorter time, lower frequency, and smaller total

Variant	Total ($n=5016$)	Non-anxiety ($n=3112$)	Anxiety ($n=1904$)	Comparison between groups		
				t /χ^2	p	Effect size
Anxiety (score)	3.560 ± 3.948	0.950 ± 1.367	7.820 ± 2.962	− 111.346	<0.001	2.119
BMI(kg/m^2)	22.004 ± 4.113	22.020 ± 4.174	21.978 ± 4.132	0.347	0.729	4.114
Age (years)	19.410 ± 1.261	19.390 ± 1.280	19.450 ± 1.228	− 1.664	0.096	1.261
Gender (male%)	0.473	0.499	0.431	22.355	<0.001	0.067
Alcohol consumption (yes%)	0.218	0.206	0.237	− 6.987	0.008	0.037
Smoking (yes%)	0.059	0.058	0.061	− 0.162	0.687	0.006
Single parent (yes%)	0.093	0.092	0.094	− 0.083	0.773	0.004
Family status				174.768	< 0.001	0.187
Good	0.649	0.711	0.289			
Normal	0.308	0.535	0.465			
Poor	0.043	0.465	0.535			
Coursework pressure				130.520	< 0.001	0.161
Easy	0.261	0.728	0.272			
Medium	0.567	0.656	0.344			
Difficult	0.172	0.491	0.509			
Social activities				63.424	< 0.001	0.112
Never	0.156	0.522	0.478			
≤ 3 times/week	0.775	0.667	0.333			
> 3 times/week	0.068	0.694	0.306			

Table 1. Demographic characteristics of university students with different anxiety levels.

Variant	Total ($n=5016$)	Non-anxiety ($n=3112$)	Anxiety ($n=1904$)	Comparison between groups		
				t	p	Cohen's d
Reward responsiveness	13.42 ± 2.04	13.74 ± 1.98	12.89 ± 2.02	209.120	<0.001	1.998
Drive	12.66 ± 2.31	13.07 ± 2.33	11.99 ± 2.11	274.071	<0.001	2.248
Fun seeking	15.58 ± 2.65	15.88 ± 2.73	15.10 ± 2.43	105.869	<0.001	2.618
Behavioural inhibition	15.32 ± 2.77	15.19 ± 2.97	15.52 ± 2.39	16.356	<0.001	2.766
Intensity	2.29 ± 1.20	2.39 ± 1.21	2.12 ± 1.16	60.304	<0.001	1.189
Duration	2.22 ± 1.27	2.33 ± 1.27	2.03 ± 1.26	65.811	<0.001	1.265
Frequency	3.06 ± 0.98	3.11 ± 0.95	2.99 ± 1.02	18.095	<0.001	0.978
Volume	19.61 ± 20.17	21.47 ± 20.90	16.56 ± 18.52	71.135	<0.001	20.032

Table 2. Comparison of anxiety scores, behavioral Inhibition and activation, and physical activity between groups of college students with different anxiety levels.

exercise. Independent t-tests showed that the differences between groups were greater than the differences within groups ($p < 0.001$).

One-way ANOVA showed that the drive, fun seeking and behavioural inhibition scores were significantly higher in the male non-anxious group than in the female non-anxious group; whereas the reward responsiveness and behavioural inhibition scores were significantly lower in the male anxious group than in the female anxious group; and the exercise volume was higher in the males than in the females, as detailed in Table 3. In particular, anxiety, exercise volume, and intensity had large effect sizes ($\eta^2 > 0.14$). Exercise duration had a medium effect size ($\eta^2 > 0.06$).

Relationships between physical activity and anxiety, behavioural Inhibition and activation systems in college students

Pearson's correlation coefficients were used to examine the relationship between physical activity level, anxiety and behavioural inhibition and activation system of college students. Anxiety is positively correlated with BIS and negatively correlated with BAS, with small differences between male and female (Fig. 2).The correlations between physical activity and the behavioural inhibition system varied across gender groups, although the correlations between physical activity frequency and the behavioral inhibition system were slightly higher for male students than for female students. Physical activity was significantly negatively correlated with anxiety,

Variant	Non-anxiety M (1554)	Anxiety M (820)	Non-anxiety F (1558)	Anxiety F (1084)	Comparison between groups			Post-hoc comparison
					F	*p*	η^2	
Anxiety (score)	0.76 ± 1.26	7.76 ± 2.77	1.15 ± 1.44	7.87 ± 3.10	4163.535	<0.001	0.714	2>3>1 4>3>1
Reward responsiveness	13.69 ± 2.14	12.51 ± 2.01	13.78 ± 1.81	13.19 ± 1.98	89.384	<0.001	0.051	1>4>2 3>4>2
Drive	13.18 ± 2.45	11.94 ± 2.12	12.96 ± 2.20	12.03 ± 2.10	94.162	<0.001	0.053	1>3>2 1>3>4
Fun seeking	16.08 ± 2.90	14.98 ± 2.42	15.68 ± 2.52	15.19 ± 2.44	42.225	<0.001	0.025	1>3>2 1>3>4
Behavioural inhibition	15.42 ± 3.23	15.18 ± 2.35	14.96 ± 2.68	15.77 ± 2.39	19.824	<0.001	0.012	4>1>2 4>1>3
Intensity	2.78 ± 1.21	2.46 ± 1.23	2.00 ± 1.07	1.86 ± 1.04	190.319	<0.001	0.102	1>2>3>4
Duration	2.67 ± 1.25	2.34 ± 1.31	1.99 ± 1.19	1.80 ± 1.18	131.936	<0.001	0.073	1>2>3>4
Frequency	3.24 ± 0.94	3.10 ± 1.03	2.98 ± 0.94	2.90 ± 1.00	32.294	<0.001	0.019	1>2>3 1>2>4
Volume	28.73 ± 23.25	22.70 ± 22.17	14.23 ± 15.12	11.91 ± 13.44	229.542	<0.001	0.121	1>2>3>4

Table 3. Comparison of anxiety scores, behavioural Inhibition and activation, and physical activity scores of male and female colloge students at different levels of anxiety.

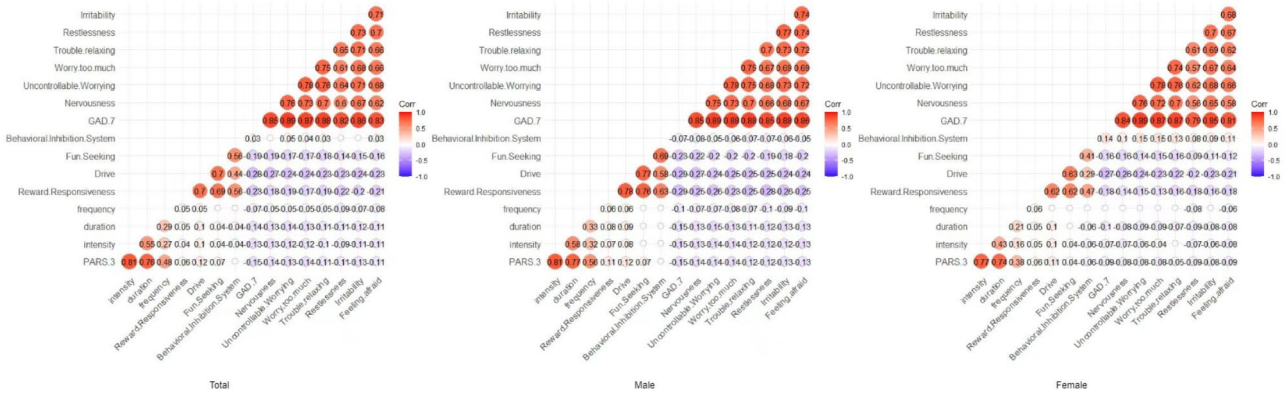

Fig. 2. Heat map of correlation coefficients between physical activity and anxiety, behavioural inhibition and activation in college students.

weakly correlated with the behavioural inhibition system, and significantly positively correlated with behavioural activation-reward responsiveness, drive, and fun seeking, which provided the basis for the construction of the subsequent mediation model.

Predictive effects of physical activity level, behavioural Inhibition and activation on anxiety

To examine the predictive effects of physical activity, behavioural inhibition and activation together on anxiety and to explore the feasibility of the structural relationship model, three models were constructed for multiple linear regression analysis using stepwise regression.

Our previous calculations indicated that family status, coursework stress, and social activities were important factors influencing anxiety symptoms, so we controlled for these factors as covariates.

Model 1 (Table 4) was analysed by multiple linear regression with physical activity (exercise intensity, duration, frequency) as the independent variable and anxiety as the dependent variable. The results showed that in the total group, exercise intensity (Beta = − 0.073, $p < 0.001$) and exercise duration (Beta = − 0.094, $p < 0.001$) were predictive of anxiety in college students, and the regression coefficient for exercise frequency (Beta = − 0.027, $p = 0.070$) was not significant. The male group performed consistently with the total group, with more exercise intensity (Beta = − 0.032, $p = 0.143$) regression coefficients not significant in the female group. Higher exercise intensity and longer exercise duration were associated with lower anxiety levels in males, and the strongest associations were found between exercise intensity and anxiety levels in males (Beta = − 0.088, $p = 0.001$); and exercise duration was most strongly associated with anxiety levels in females (Beta = − 0.084, $p < 0.001$). After controlling for confounders, the relationship between physical activity hours and anxiety symptoms in boys was no longer significant, and the relationship between the remaining independent variables and anxiety symptoms still held.

Model 2 (Table 5) was subjected to multiple linear regression analysis with behavioural inhibition and activation (reward responsiveness, drive, fun seeking, and behavioral inhibition) as independent variables and

Crowd	Model	Independent variable	B	SE	95%CI		Beta	t	p	VIF	model summary
					Lower	Upper					
Total	A	Constant	5.084	0.192	4.708	5.461		26.477	<0.001		$R^2=0.025$ $adj\text{-}R^2=0.024$ $F=42.421$, $p<0.001$ Durbin-Watson = 1.948
		Intensity	-0.241	0.056	-0.350	-0.132	-0.073	-4.335	<0.001	1.455	
		Duration	-0.290	0.053	-0.393	-0.187	-0.094	-5.519	<0.001	1.477	
		Frequency	-0.108	0.059	-0.224	0.009	-0.027	-1.815	0.070	1.113	
	B	Constant	2.244	0.420	1.420	3.067		5.343	<0.001	1.462	$R^2=0.083$ $adj\text{-}R^2=0.081$ $F=57.592$, $p<0.001$ Durbin-Watson = 1.977
		Intensity	-0.153	0.061	-0.272	-0.033	-0.047	-2.500	0.012	1.483	
		Duration	-0.152	0.059	-0.266	-0.037	-0.049	-2.587	0.010	1.128	
		Frequency	-0.086	0.066	-0.217	0.044	-0.021	-1.297	0.195	1.042	
		家庭	1.138	0.109	0.924	1.351	0.165	10.448	<0.001	1.062	
		课业	0.829	0.096	0.641	1.017	0.138	8.634	<0.001	1.059	
		社交	-0.590	0.134	-0.853	-0.327	-0.070	-4.398	<0.001	1.462	
Male	A	Constant	5.045	0.283	4.489	5.601		17.796	<0.001	1.551	$R^2=0.029$ $adj\text{-}R^2=0.028$ $F=23.689$, $p<0.001$ Durbin-Watson = 1.968
		Intensity	-0.275	0.079	-0.430	-0.120	-0.088	-3.480	0.001	1.568	
		Duration	-0.251	0.076	-0.401	-0.102	-0.084	-3.297	0.001	1.157	
		Frequency	-0.154	0.086	-0.322	0.014	-0.039	-1.799	0.072	1.551	
	B	Constant	2.769	0.572	1.646	3.891		4.837	<0.001		$R^2=0.066$ $adj\text{-}R^2=0.063$ $F=21.291$, $p<0.001$ Durbin-Watson = 2.008
		Intensity	-0.257	0.088	-0.429	-0.085	-0.082	-2.927	0.003	1.508	
		Duration	-0.122	0.087	-0.292	0.047	-0.04	-1.414	0.157	1.529	
		Frequency	-0.109	0.098	-0.301	0.082	-0.028	-1.121	0.262	1.172	
		家庭	1.156	0.168	0.827	1.485	0.159	6.891	<0.001	1.036	
		课业	0.481	0.133	0.220	0.742	0.084	3.615	<0.001	1.050	
		社交	-0.423	0.186	-0.787	-0.058	-0.054	-2.276	0.023	1.081	
Female	A	Constant	4.821	0.273	4.286	5.357		17.652	<0.001		$R^2=0.011$ $adj\text{-}R^2=0.010$ $F=9.739$, $p<0.001$ Durbin-Watson = 1.971
		Intensity	-0.120	0.082	-0.281	0.040	-0.032	-1.467	0.143	1.240	
		Duration	-0.282	0.073	-0.425	-0.138	-0.084	-3.843	<0.001	1.263	
		Frequency	-0.048	0.082	-0.210	0.113	-0.012	-0.588	0.556	1.053	
	B	Constant	1.606	0.617	0.396	2.816		2.602	0.009		$R^2=0.092$ $adj\text{-}R^2=0.089$ $F=33.547$, $p<0.001$ Durbin-Watson = 1.935
		Intensity	-0.020	0.090	-0.196	0.155	-0.005	-0.229	0.819	1.242	
		Duration	-0.161	0.081	-0.319	-0.002	-0.048	-1.991	0.047	1.266	
		Frequency	-0.062	0.091	-0.24	0.117	-0.015	-0.677	0.498	1.057	
		家庭	1.111	0.145	0.826	1.395	0.166	7.656	<0.001	1.028	
		课业	1.175	0.139	0.902	1.447	0.184	8.45	<0.001	1.048	
		社交	-0.741	0.195	-1.123	-0.359	-0.083	-3.808	<0.001	1.055	

Table 4. Multiple linear regression analysis of physical activity on anxiety symptoms. A is the original model, B is the model controlling for confounders (family relationships, interpersonal relationships, frequency of socialisation)

anxiety as dependent variable. The results showed that in the total group, reward (Beta = − 0.167, $p<0.001$) and drive (Beta = − 0.236, $p<0.001$) were negatively predictive of college students' anxiety; behavioural inhibition (Beta = 0.264, $p<0.001$) was positively predictive; and fun seeking (Beta = − 0.061, $p=0.004$) regression coefficients were not significant. The gender groups performed consistently with the total group, with reward responsiveness having the strongest association with anxiety levels in males (Beta = − 0.255, $p<0.001$); and behavioural inhibition having the strongest association with anxiety levels in females (Beta = 0.291, $p<0.001$). After controlling for confounders, the relationship between the independent variables and anxiety symptoms remained valid.

Model 3 (Table 6) was subjected to multiple linear regression analysis with physical activity level (exercise intensity, duration, frequency), behavioural inhibition and activation (reward responsiveness, drive, fun seeking, behavioural inhibition) as independent variables and anxiety as dependent variable. The total group results showed that the regression model passed the test of significance ($F_{(4,\ 5011)}$ = 112.039, $p<0.001$, $R^2=0.135$), and that exercise intensity (Beta = − 0.048, $p=0.002$), exercise duration (Beta = − 0.066, $p<0.001$), reward responsiveness (Beta = − 0.165, $p<0.001$), drive (Beta = − 0.217, $p<0.001$), fun seeking (Beta = − 0.063, $p=0.003$), and behavioural inhibition (Beta = 0.251, $p<0.001$) were all predictive of anxiety in college students, whereas regression coefficients for exercise frequency (Beta = − 0.020, $p=0.155$) were not significant. After controlling for confounders, the length of physical activity was no longer significant, the frequency of physical activity remained significant for male students, and the intensity of physical activity was no longer significant for female students.

Model	Crowd	Independent variable	B	SE	95%CI		Beta	t	*p*	VIF	model summary
					Lower	Upper					
Total	A	Constant	8.656	0.374	7.923	9.389		23.153			$R^2=0.124$ $adj\text{-}R^2=0.123$ $F=176.980$ $p<0.001$ Durbin-Watson = 1.930
		Reward responsiveness	-0.323	0.040	-0.402	-0.244	-0.167	-7.985	<0.001	2.491	
		Drive	-0.404	0.035	-0.472	-0.335	-0.236	-11.498	<0.001	2.407	
		Fun seeking	-0.090	0.031	-0.152	-0.029	-0.061	-2.877	0.004	2.536	
		Behavioural inhibition	0.376	0.024	0.329	0.422	0.264	15.828	<0.001	1.585	
	B	Constant	3.797	0.507	2.804	4.791		7.493	<0.001		$R^2=0.173$ $adj\text{-}R^2=0.171$ $F=113.903$ $p<0.001$ Durbin-Watson = 1.962
		Reward responsiveness	-0.254	0.047	-0.347	-0.162	-0.131	-5.403	< 0.001	2.711	
		Drive	-0.322	0.041	-0.402	-0.243	-0.189	-7.949	< 0.001	2.609	
		Fun seeking	-0.100	0.035	-0.169	-0.031	-0.068	-2.832	0.005	2.667	
		Behavioural inhibition	0.325	0.028	0.271	0.379	0.232	11.791	< 0.001	1.794	
		家庭	0.787	0.106	0.578	0.995	0.114	7.399	<0.001	1.101	
		课业	0.574	0.092	0.393	0.755	0.095	6.227	< 0.001	1.085	
		社交	1.123	0.134	0.86	1.385	0.133	8.387	< 0.001	1.166	
Male	A	Constant	9.425	0.480	8.483	10.367		19.617	<0.001		$R^2=0.122$ $adj\text{-}R^2=0.120$ $F=82.000$, $p<0.001$ Durbin-Watson = 1.962
		Reward responsiveness	-0.451	0.061	-0.570	-0.332	-0.255	-7.441	<0.001	3.157	
		Drive	-0.290	0.054	-0.396	-0.183	-0.182	-5.319	<0.001	3.143	
		Fun seeking	-0.075	0.049	-0.171	0.020	-0.055	-1.545	0.122	3.373	
		Behavioural inhibition	0.301	0.035	0.231	0.370	0.231	8.472	<0.001	2.008	
	B	Constant	7.455	0.733	6.017	8.892		10.172	<0.001		$R^2=0.134$ $adj\text{-}R^2=0.131$ $F=40.166$ $p<0.001$ Durbin-Watson = 1.996
		Reward responsiveness	-0.371	0.071	-0.51	-0.231	-0.211	-5.217	<0.001	3.426	
		Drive	-0.279	0.064	-0.405	-0.154	-0.174	-4.371	<0.001	3.322	
		Fun seeking	-0.071	0.056	-0.181	0.04	-0.053	-1.256	0.209	3.667	
		Behavioural inhibition	0.264	0.043	0.18	0.349	0.209	6.142	<0.001	2.419	
		家庭	0.9	0.163	0.579	1.22	0.124	5.506	<0.001	1.060	
		课业	0.377	0.128	0.125	0.629	0.066	2.936	0.003	1.054	
		社交	-0.411	0.175	-0.755	-0.067	-0.052	-2.344	0.019	1.040	
	Female	Constant	7.529	0.581	6.389	8.669		12.949	<0.001		$R^2=0.173$ $adj\text{-}R^2=0.171$ $F=113.903$ $p<0.001$ Durbin-Watson = 1.926
		Reward responsiveness	-0.311	0.055	-0.418	-0.203	-0.148	-5.648	<0.001	2.085	
		Drive	-0.429	0.046	-0.519	-0.339	-0.236	-9.338	<0.001	1.956	
		Fun seeking	-0.057	0.041	-0.138	0.023	-0.036	-1.393	0.164	2.017	
		Behavioural inhibition	0.449	0.032	0.386	0.513	0.291	13.908	<0.001	1.332	
		Constant	4.245	0.833	2.611	5.880		5.095	<0.001		$R^2=0.182$ $adj\text{-}R^2=0.179$ $F=63.445$, $p<0.001$ Durbin-Watson = 1.908
		Reward responsiveness	-0.266	0.064	-0.392	-0.140	-0.125	-4.147	<0.001	2.209	
		Drive	-0.346	0.053	-0.450	-0.242	-0.193	-6.503	<0.001	2.139	
		Fun seeking	-0.082	0.046	-0.173	0.008	-0.052	-1.783	0.075	2.067	
		Behavioural inhibition	0.409	0.037	0.337	0.482	0.268	11.044	<0.001	1.436	
		家庭	0.909	0.139	0.637	1.182	0.136	6.547	<0.001	1.046	
		课业	0.901	0.133	0.640	1.161	0.141	6.77	<0.001	1.065	
		社交	-0.417	0.185	-0.781	-0.054	-0.047	-2.253	0.024	1.06	

Table 5. Multiple linear regression analysis of behavioural Inhibition and activation on anxiety symptoms. A is the original model, B is the model controlling for confounders (family relationships, interpersonal relationships, frequency of socialisation)

The *p*-values of all three models were significant. And the VIF values of all independent variables in the model were less than 5, indicating that the results of this study can basically exclude the influence of multiple covariance, as shown in Table 4. Multiple linear regression analyses showed that physical activity, behavioural inhibition system and activation all had a predictive effect on college students' anxiety symptoms. However, the predictive effects of exercise frequency and fun seeking were not obvious. Exercise intensity did not have a predictive effect on female college students' anxiety symptoms. Exercise intensity and exercise duration were strongly associated with anxiety levels of male and female college students, respectively.

Analysis of the mediating effects of behavioural Inhibition and activation on anxiety

Firstly, Harman's one-way test was used to test for common method bias. The results showed that the analysis of the overall data yielded five factors with characteristic roots greater than 1, and the variance explained rate of the first common factor was 29.122%; the analysis of the data of male college students yielded four factors with characteristic roots greater than 1, and the variance explained rate of the first common factor was 33.791%;

Model	Crowd	Independent variable	B	SE	95%CI		Beta	t	*p*	VIF	model summary
					Lower	Upper					
Total	A	Constant	9.595	0.404	8.803	10.387		23.755	<0.001		$R^2 = 0.135$ $adj\text{-}R^2 = 0.134$ $F = 112.039$ $p<0.001$ Durbin-Watson = 1.934
		Intensity	-0.160	0.052	-0.263	-0.057	-0.048	-3.048	0.002	1.463	
		Duration	-0.205	0.050	-0.303	-0.108	-0.066	-4.134	<0.001	1.486	
		Frequency	-0.080	0.056	-0.189	0.030	-0.020	-1.422	0.155	1.117	
		Reward responsiveness	-0.319	0.040	-0.398	-0.240	-0.165	-7.930	<0.001	2.498	
		Drive	-0.372	0.035	-0.441	-0.303	-0.217	-10.601	<0.001	2.437	
		Fun seeking	-0.094	0.031	-0.155	-0.032	-0.063	-3.000	0.003	2.539	
		Behavioural inhibition	0.358	0.024	0.311	0.404	0.251	15.109	<0.001	1.599	
	B	Constant	6.562	0.575	5.435	7.690		11.412	<0.001		$R^2 = 0.164$ $adj\text{-}R^2 = 0.161$ $F = 74.707$ $p<0.001$ Durbin-Watson = 1.947
		Intensity	-0.096	0.058	-0.210	0.019	-0.029	-1.639	0.101	1.466	
		Duration	-0.115	0.056	-0.225	-0.005	-0.037	-2.042	0.041	1.489	
		Frequency	-0.059	0.064	-0.184	0.066	-0.015	-0.929	0.353	1.131	
		Reward responsiveness	-0.288	0.047	-0.380	-0.195	-0.148	-6.102	<0.001	2.693	
		Drive	-0.323	0.041	-0.403	-0.243	-0.189	-7.897	<0.001	2.622	
		Fun seeking	-0.104	0.035	-0.173	-0.034	-0.071	-2.920	0.004	2.673	
		Behavioural inhibition	0.336	0.028	0.282	0.391	0.241	12.152	<0.001	1.793	
		家庭	0.920	0.105	0.714	1.126	0.134	8.755	<0.001	1.063	
		课业	0.631	0.093	0.450	0.812	0.105	6.820	<0.001	1.080	
		社交	-0.340	0.129	-0.593	-0.088	-0.040	-2.640	0.008	1.071	
Male	A	Constant	10.583	0.531	9.542	11.625		19.925	<0.001		$R^2 = 0.136$ $adj\text{-}R^2 = 0.134$ $F = 53.341$, $p<0.001$ Durbin-Watson = 1.971
		Intensity	-0.207	0.075	-0.354	-0.061	-0.066	-2.772	0.006	1.558	
		Duration	-0.174	0.072	-0.316	-0.033	-0.058	-2.418	0.016	1.576	
		Frequency	-0.106	0.081	-0.265	0.052	-0.027	-1.314	0.189	1.159	
		Reward responsiveness	-0.422	0.060	-0.541	-0.304	-0.238	-7.003	<0.001	3.175	
		Drive	-0.262	0.054	-0.369	-0.156	-0.165	-4.843	<0.001	3.163	
		Fun seeking	-0.087	0.048	-0.182	0.008	-0.063	-1.803	0.072	3.378	
		Behavioural inhibition	0.277	0.035	0.208	0.347	0.213	7.834	<0.001	2.030	
	B	Constant	8.138	0.767	6.632	9.643		10.604	<0.001		$R^2 = 0.142$ $adj\text{-}R^2 = 0.137$ $F = 29.886$, $p<0.001$ Durbin-Watson = 2
		Intensity	-0.195	0.084	-0.361	-0.029	-0.062	-2.309	0.021	1.519	
		Duration	-0.103	0.083	-0.266	0.06	-0.033	-1.238	0.216	1.532	
		Frequency	-0.046	0.094	-0.23	0.138	-0.012	-0.491	0.624	1.177	
		Reward responsiveness	-0.35	0.071	-0.489	-0.211	-0.199	-4.925	<0.001	3.449	
		Drive	-0.266	0.064	-0.391	-0.141	-0.166	-4.166	<0.001	3.333	
		Fun seeking	-0.077	0.056	-0.187	0.033	-0.057	-1.372	0.170	3.671	
		Behavioural inhibition	0.248	0.043	0.164	0.333	0.196	5.751	<0.001	2.446	
		家庭	0.883	0.163	0.563	1.203	0.121	5.413	<0.001	1.063	
		课业	0.338	0.129	0.086	0.59	0.059	2.63	0.009	1.062	
		社交	-0.267	0.179	-0.618	0.084	-0.034	-1.491	0.136	1.089	

Continued

Model	Crowd	Independent variable	B	SE	95%CI		Beta	t	p	VIF	model summary
					Lower	Upper					
Female	A	Constant	7.875	0.622	6.656	9.094		12.665	<0.001		$R^2=0.138$ $adj\text{-}R^2=0.136$ $F=60.345$ $p<0.001$ Durbin-Watson = 1.925
		Intensity	0.009	0.077	-0.142	0.159	0.002	0.114	0.909	1.249	
		Duration	-0.167	0.069	-0.302	-0.032	-0.050	-2.430	0.015	1.274	
		Frequency	-0.031	0.077	-0.182	0.120	-0.007	-0.403	0.687	1.059	
		Reward responsiveness	-0.305	0.055	-0.413	-0.196	-0.145	-5.526	<0.001	2.098	
		Drive	-0.418	0.046	-0.508	-0.327	-0.230	-9.043	<0.001	1.979	
		Fun seeking	-0.061	0.041	-0.142	0.020	-0.038	-1.487	0.137	2.023	
		Behavioural inhibition	0.442	0.032	0.378	0.505	0.286	13.604	<0.001	1.347	
	B	Constant	4.438	0.869	2.733	6.143		5.105	<0.001		$R^2=0.183$ $adj\text{-}R^2=0.179$ $F=44.607$, $p<0.001$ Durbin-Watson = 1.906
		Intensity	0.06	0.085	-0.107	0.227	0.016	0.706	0.480	1.247	
		Duration	-0.09	0.077	-0.240	0.061	-0.027	-1.167	0.243	1.274	
		Frequency	-0.06	0.087	-0.230	0.110	-0.014	-0.692	0.489	1.064	
		Reward responsiveness	-0.264	0.064	-0.390	-0.137	-0.124	-4.098	<0.001	2.220	
		Drive	-0.342	0.053	-0.447	-0.237	-0.19	-6.398	<0.001	2.157	
		Fun seeking	-0.086	0.046	-0.177	0.005	-0.054	-1.857	0.063	2.077	
		Behavioural inhibition	0.408	0.037	0.335	0.481	0.267	10.973	<0.001	1.445	
		家庭	0.912	0.139	0.639	1.184	0.136	6.559	<0.001	1.047	
		课业	0.894	0.134	0.632	1.156	0.14	6.696	<0.001	1.073	
		社交	-0.397	0.186	-0.762	-0.031	-0.045	-2.128	0.033	1.072	

Table 6. Multiple linear regression analysis of physical activity, behavioural Inhibition and activation on anxiety symptoms. A is the original model, B is the model controlling for confounders (family relationships, interpersonal relationships, frequency of socialisation)

and the analysis of female college students yielded five factors with characteristic roots greater than 1, and the variance explained rate of the first common factor was 25.185%, all these three values were less than 40% of the critical value, which indicated that there is no serious common method bias in this study.

The interrelationships of physical activity, behavioural inhibition and activation, and anxiety symptoms among college students were used as the basis to test the research hypotheses. Model 1 was established with physical activity as the independent variable, behavioural inhibition and activation as the mediator variable, and anxiety as the dependent variable, and then 2 sub-models were established with the data of male and female college student groups respectively. Paths with non-significant coefficients were eliminated one by one and recalculated until all path coefficients passed the Bootstrap significance test. Repeating this process, the results of the path analysis are shown in Fig. 3, and the results of the mediation effect test are shown in Table 5.

Referring to the reference criteria of CMIN/df < 5, RMR < 0.05, RMSEA < 0.08 and GFI, NFI and CFI values > 0.9[35,43]. Model 1 has CMIN/df = 6.865, indicating a good model fit, and the 2 sub-models have CMIN/df < 5, which is a good model fit. The rest of the goodness-of-fit metrics of the 3 models are fully compliant with the criteria, indicating that the structural equation models are reasonable and reliable.

Three measures had factor loadings greater than 1.00 on physical activity; four measures had factor loadings between 0.81 and 1.03 on behavioural inhibition and activation; and seven measures had factor loadings between 0.85 and 1.07 on behavioral inhibition and activation. All loadings reached significance at the $\alpha = 0.001$ level. This indicates that these measures can better characterise the various potential qualities of the study's predictors.

Direct effects of physical activity on anxiety

Physical activity had a direct effect on reducing anxiety by 84.37% (effect size −0.286, 95% bootstrap CI:=[-0.366,-0.213]), as shown in Table 5. Physical activity had a significant predictive effect on anxiety for both sexes and was more predictive for the female cohort. In terms of factor loading values for each measure, exercise duration (M:1.81; F:2.71) was more important than exercise intensity (M:1.74; F:2.07), and frequency (M:1.00; F:1.00) in the manifestation of anxiolytic symptoms. Details are in Fig. 3b, c. Specifically, it was shown to be more effective in alleviating the four dimensions of uncontrollable worrying (1.07), worry too much (1.03), trouble relaxing (1.00), and nervousness (1.00), with less difference in values between the male and female groups. Details are in Fig. 3a. Physical activity was more effective in alleviating anxiety symptoms of male college students in the dimensions of feeling afraid (M:0.96; F:0.88), restlessness (M:0.94; F:0.82). Details are in Fig. 3b, c.

Mediating effects of behavioural Inhibition and activation system

The mediating effect of behavioural inhibition and activation between physical activity and anxiety was significant (effect value −0.053, contribution to effect 15.63%, 95% bootstrap CI=[-0.079,-0.030]), as shown in Table 5. Behavioural inhibition and activation mediated in both sexes and anxiety symptoms were more controlled by behavioural inhibition and activation in the female group (29.92%) than in the male group (15.76%) were more controlled by behavioural inhibition versus activation. In terms of factor loading values for each measure,

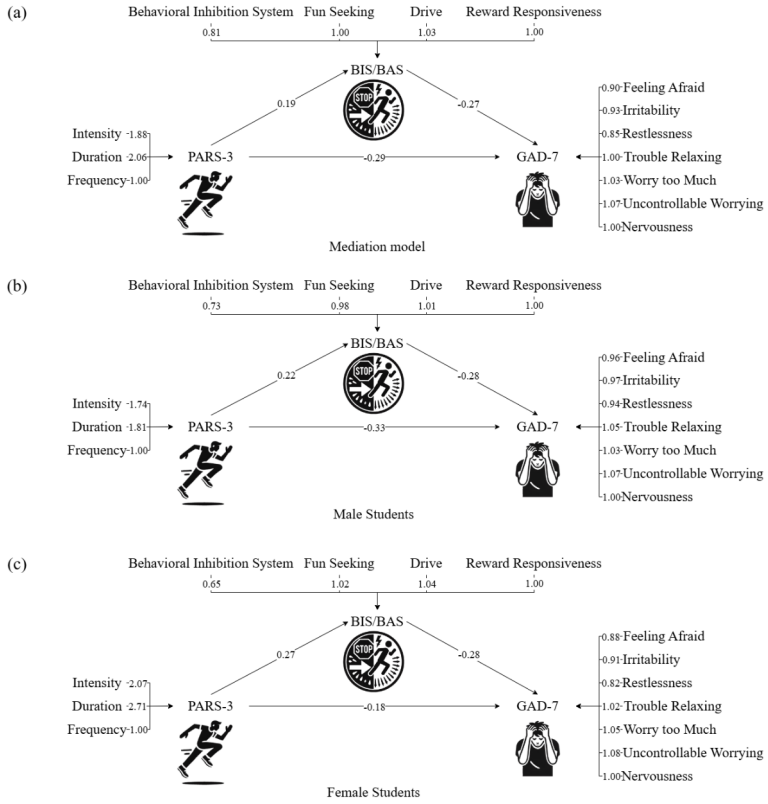

Fig. 3. Schematic diagram of the path analysis of physical activity levels affecting anxiety through the behavioural inhibition and activation system.

Model	Effect type	B	Bootstrap SE	Z	Bias-Corrected 95%CI	*p*	Percentage of effect	Goodness of fit of the model
Model 1 (Total)	Total effect	-0.339	0.040	-8.475	[-0.422,-0.263]	<0.001	100%	CMIN/df = 6.865 RMR = 0.023 RMSEA = 0.034 GFI = 0.988 NFI = 0.990 CFI = 0.991
	Direct effect	-0.286	0.039	-7.333	[-0.366,-0.213]	<0.001	84.37%	
	Behavioural inhibition and activation mediation	-0.053	0.012	-4.417	[-0.079,-0.030]	<0.001	15.63%	
Model 2 (Male)	Total effect	-0.387	0.055	-7.036	[-0.500,-0.285]	<0.001	100%	CMIN/df = 3.483 RMR = 0.034 RMSEA = 0.032 GFI = 0.987 NFI = 0.990 CFI = 0.993
	Direct effect	-0.326	0.052	-6.269	[-0.434,-0.229]	<0.001	84.24%	
	Behavioural inhibition and activation mediation	-0.061	0.017	-3.588	[-0.098,-0.031]	<0.001	15.76%	
Model 3 (Female)	Total effect	-0.254	0.079	-3.215	[-0.418,-0.104]	0.001	100%	CMIN/df = 4.904 RMR = 0.029 RMSEA = 0.038 GFI = 0.983 NFI = 0.984 CFI = 0.987
	Direct effect	-0.178	0.076	-2.342	[-0.336,-0.032]	0.020	70.08%	
	Behavioural inhibition and activation mediation	-0.076	0.025	-3.040	[-0.130,-0.032]	0.001	29.92%	

Table 7. Bootstrap test results for mediation effects.

drive (M:1.01; F:1.04) was better than behavioural inhibition (M:0.73; F:0.65), fun seeking (M:0.98; F:1.02), and reward responsiveness (M:1.00; F:1.00) in the performance of anxiolytic symptoms, as shown in Fig. 3b, c.

Discussion

This study not only examined the predictive roles of gender and physical activity on BIS/BAS, and validated the direct effects of PA on anxiety, but also revealed the mediating role of BIS/BAS, providing new evidence for understanding how PA affects anxiety symptoms through neuropsychological mechanisms. This study had a large sample size and strict process control. The results mainly found the explanation of behavioural inhibition and activation and physical activity on anxiety of college students of different genders. It is expected to provide theoretical support and guiding significance for the study of college students' psychological state or the construction of physical education programmes in universities.

The present study found that the anxiety symptomatic population had lower intensity, shorter duration, lower frequency, and smaller volume in physical activities; the anxiety symptomatic population showed lower scores in reward responsiveness, drive, and fun seeking, and higher scores in behavioural inhibition, which was consistent with previous studies[44,45], and verified hypothesis a. In addition, the effect sizes of family status, coursework pressure, and social activities were larger in the comparison of anxious versus non-anxious college students. This study further found that there was a significant difference in gender between the non-anxious and anxious groups, with females having a higher prevalence of anxiety symptoms, which also verified the previous studies[46,47]. Physical activity is effective in stimulating the central nervous system[48,49], increasing self-efficacy, and enhancing emotional regulation in situations of stress and anxiety[7,50,51]. Therefore the difference in scores in the non-anxiety group may be related to the fact that men exercise more than women[52].

The present study found that physical activity of college students was significantly negatively correlated with anxiety, which is consistent with the results of a previous study[53]. And the correlation coefficients between anxiety and the amount, intensity, and duration of exercise were greater. College students' physical activity was weakly correlated with the behavioral inhibition system, and significantly positively correlated with behavioral activation-reward responsiveness, drive, and fun seeking, consistent with the findings of Firoozjah et al.[54], which to some extent verified hypothesis b. And the correlation coefficients between anxiety and BAS-reward responsiveness, drive, and fun seeking were greater compared to BIS. A large number of scholars have explored the intrinsic mechanisms of exercise to improve mood from physiological and psychological mechanisms. And the results of the present study provide a new perspective for the field that the behavioural inhibition and activation system (mainly the behavioural activation system) may be the potential pathway of action for the improvement of anxiety symptoms after physical activity.

The present study supported that physical activity, behavioural inhibition and activation were all predictive of college students' anxiety symptoms, which was consistent with previous studies[44,48,55,56], and verified hypothesis c. The present study further found that, in the physical activity dimension, exercise frequency and fun seeking were not significant predictors of college students' anxiety symptoms. And exercise intensity was not predictive of anxiety symptoms in female college students. Exercise intensity and exercise duration were strongly associated with anxiety levels of male and female college students, respectively. In the behavioural inhibition and activation dimensions, this study further found gender differences in BIS/BAS reactivity. By making gender comparisons in the anxiety symptom group: Charles et al. concluded that females scored significantly higher than males on BIS responsiveness[57–59]. Functional magnetic resonance imaging (fMRI) studies have shown that women have stronger connections between the prefrontal cortex (PFC) and the amygdala, which may make them more sensitive to negative emotions[60]. This may explain why BIS is a stronger predictor of anxiety in women. Carver and White found that females scored higher than males on BAS reward responsiveness in a sample of college students[57]. By making gender comparisons in the non-anxiety symptom group: Verbeken et al. found that males scored slightly higher than females on the BAS drive[61]. The study further builds on previous research by finding that the male non-anxiety group had similarly significantly higher scores on fun seeking and behavioural inhibition system than the female non-anxiety group.

The important finding of the present study is that physical activity can indirectly affect anxiety symptoms by acting on the behavioural inhibition and activation system with gender differences. Guyer et al. identified areas of brain activity associated with reward and punishment including the ventral striatum, hippocampus, hypothalamus, and insula, which are associated with emotional processing[62]. This explains the mediating role of behavioural inhibition and activation systems in anxiety symptoms in both sexes[63]. From a neuroanatomical point of view, females have higher BIS sensitivity and higher FC (Functional connectivity) between the seed areas of the ventral medial prefrontal cortex and the posterior parietal areas compared to males; this FC mediates the effect of gender on BIS sensitivity[60]. As a result, anxiety symptoms are more controlled by the behavioural inhibition and activation system in the female population than in the male population[64]. In addition, consistent with previous work[65] the present study also found that exercise time was more important in the expression of anxiolytic symptoms. This was shown to be more effective in alleviating the four dimensions of uncontrollable worrying (GAD2), worry too much (GAD3), trouble relaxing (GAD4), and nervousness (GAD1). Feeling afraid (GAD7), restlessness (GAD5) anxiety symptom dimensions had a greater effect on anxiety symptoms among male college students.

Through a large sample and strictly controlled experimental design, this study verified the alleviating effect of physical activity on anxiety, and revealed the gender differences in the BIS/BAS system and its mechanism of action in anxiety symptoms. The results of the study can directly provide a scientific basis for anxiety intervention for college students and have the following practical implications. ① Promote individualised exercise intervention and optimise the design of physical education curriculum in colleges. For males, high intensity and prolonged exercise (e.g., aerobic training of more than 60 min) was emphasized to enhance fun seeking and drive, and to increase the activity of the behavioural activation system. For females, the emphasis is on moderate-intensity, long-duration exercise (e.g., yoga, jogging) to reduce behavioural inhibition and improve anxiety relief. ② Precision intervention for anxiety symptoms. For individuals whose anxiety is accompanied by nervousness, meditative exercises such as yoga and tai chi are recommended to reduce BIS sensitivity. For individuals with worry too much, rhythmic exercises, such as jogging and swimming, are recommended to enhance BAS drive and improve emotional stability. By accurately matching the type of anxiety symptoms with exercise modalities, it provides a new research direction for further exploring the neural mechanisms of anxiety. This not only contributes to the mental health management of college students, but also provides new theoretical support for sports intervention in anxiety disorders.

Limitations and prospects

(1) This study used the cross-sectional design, which limits causal inferences. It is recommended that more longitudinal studies be conducted in the future to further explore the time series of changes in the causal relationship between physical activity, behavioural inhibition and activation, and anxiety, and the magnitude of the related effect sizes;
(2) Physical activity in this study was measured using a self-report questionnaire, which may have some bias and it is recommended that in the future, we combine accelerometers, heart rate bands, and other measurement tools to collect information from subjects and report physical activity more accurately;
(3) The demographic diversity in this study is limited, as participant data were collected exclusively from the University Town in Songjiang District, Shanghai, which may affect the generalizability of the results.
(4) This study used the GAD-7 to measure anxiety symptoms. Some scholars have proposed a variety of anxiety symptoms such as state anxiety, trait anxiety, and social anxiety, which can be further categorised and discussed in the future according to the source and nature of anxiety.

Conclusions and recommendations

Physical activity has a direct effect on anxiety, and the anxiolytic effects of physical activity can be mediated through the behavioural inhibition and activation system, and the mediating effect is highest in the female college student population. It is recommended that psychoeducation in colleges should be combined with exercise to encourage students to engage in more physical activities, increase sensitivity to behaviourally activated coping strategies and reward messages, and alleviate anxiety symptoms. Attention should also be paid to gender differences and individualised exercise programmes should be adopted, especially for female students who are at higher risk of anxiety. In addition, in the long term, designing and conducting more engaging physical education programmes is necessary for higher education institutions in order to promote the formation of stable exercise habits among students. In the future, we hope to build on this study to explore more specific exercise improvement options for anxious college students.

Data availability

The datasets used and/or analysed during the current study available from the corresponding author on reasonable request.

Received: 4 December 2024; Accepted: 19 February 2025
Published online: 25 February 2025

References

1. Abi-Dargham, A., Moeller, S.J. & Ali, F., et al., Candidate biomarkers in psychiatric disorders: State of the field. *World Psychiatry* **22** (2), 236–262 (2023).
2. Crocq, M.-A., The history of generalized anxiety disorder as a diagnostic category. *Dialogues Clin. Neurosci.* **19** (2), 107–115 (2017).
3. Norbury, R. & Evans, S., Time to think: Subjective sleep quality, trait anxiety and university start time. *Psychiatry Res.* **271**, 214–219 (2019).
4. Lipson, S. K., Zhou, S. S. & Abelson, S., et al., Trends in college student mental health and help-seeking by race/ethnicity: Findings from the national healthy minds study, 2013–2021. *J. Affect. Disord.* **306**, 138–147 (2022).
5. Zeng, W., Chen, R. Q. & Wang, X. Y., et al., Prevalence of mental health problems among medical students in China A meta-analysis. *Medicine* **98** (18), e15337 (2019).
6. Cao, W., Fang, Z. & Hou, G., et al., The psychological impact of the COVID-19 epidemic on college students in China. *Psychiatry Res.* **287**, 112934 (2020).
7. Diotaiuti, P., Valente, G. & Mancone, S., et al., A mediating model of emotional balance and procrastination on academic performance. *Front. Psychol.* **12**, 665196 (2021).
8. Carver, C. S. & White, T. L., Behavioral-inhibition, behavioral activation, and affective responses to impending reward and punishment—the bis bas scales. *J. Pers. Soc. Psychol.* **67** (2), 319–333 (1994).
9. Scholten, M. R. M., van Honk, J. & Aleman, A., et al., Behavioral inhibition system (BIS), Behavioral activation system (BAS) and schizophrenia: Relationship with psychopathology and physiology. *J. Psychiatr. Res.* **40** (7), 638–645 (2006).
10. Johnson, S. L., Turner, R. J. & Iwata, N., BIS/BAS levels and psychiatric disorder: An epidemiological study. *J. Psychopathol. Behav. Assess.* **25** (1), 25–36 (2003).
11. Xie, J. L., Fang, P. & Zhang, Z. H., et al., Behavioral inhibition/activation systems and depression among females with substance use disorder: The mediating role of intolerance of uncertainty and anhedonia. *Front. Psychiatry* **12**, 644882 (2021).
12. Katz, B. A. & Yovel, I., Reinforcement sensitivity predicts affective psychopathology via emotion regulation: Cross-sectional, longitudinal and quasi-experimental evidence. *J. Affect. Disord.* **301**, 117–129 (2022).
13. Katz, B. A., Matanky, K. & Aviram, G., et al., Reinforcement sensitivity, depression and anxiety: A meta-analysis and meta-analytic structural equation model. *Clin. Psychol. Rev.* **77**, 101842 (2020).
14. Takahashi, Y., Yamagata, S. & Ritchie, S. J., et al., Etiological pathways of depressive and anxiety symptoms linked to personality traits: A genetically-informative longitudinal study. *J. Affect. Disord.* **291**, 261–269 (2021).
15. Li, Y., Qiao, L. & Sun, J., et al., Gender-specific neuroanatomical basis of behavioral inhibition/approach systems (BIS/BAS) in a large sample of young adults: A voxel-based morphometric investigation. *Behav. Brain Res.* **274**, 400–408 (2014).
16. Jung, Y. H., Lee, U. S. & Jang, J. H., et al., Effects of mind-body training on personality and behavioral activation and inhibition system according to BDNF Val66Met polymorphism. *Psychiatry Investig.* **13** (3), 333–340 (2016).
17. Hallgren, M., Stubbs, B. & Vancampfort, D., et al., Treatment guidelines for depression: Greater emphasis on physical activity is needed. *Eur. Psychiatry* **40**, 1–3 (2017).
18. Singh, B., Olds, T. & Curtis, R., et al., Effectiveness of physical activity interventions for improving depression, anxiety and distress: An overview of systematic reviews. *Br. J. Sports Med.* **57** (18), 1203–1209 (2023).
19. Klein, T., Bailey, T. G. & Abeln, V., et al., Cerebral blood flow during interval and continuous exercise in young and old men. *Med. Sci. Sports Exerc.* **51** (7), 1523–1531 (2019).

20. Kruk, J., Kotarska, K. & Aboul-Enein, B. H., Physical exercise and catecholamines response: benefits and health risk: Possible mechanisms. *Free Radic. Res.* **54** (2–3), 105–125 (2020).
21. BETTARIGA F, TAAFFE D R, GALVAO D A, *et al.* Exercise training mode effects on myokine expression in healthy adults: A systematic review with meta-analysis [J]. *J. of Sport and Health Science*. **13**(6), 764-79 (2024).
22. Cherian, K., Schatzberg, A. F. & Keller, J., HPA axis in psychotic major depression and schizophrenia spectrum disorders: Cortisol, clinical symptomatology, and cognition. *Schizophr. Res.* **213**, 72–79 (2019).
23. Paolucci, E. M., Loukov, D. & Bowdish, D. M. E., et al., Exercise reduces depression and inflammation but intensity matters. *Biol. Psychol.* **133**, 79–84 (2018).
24. Ma, K., Liu, J. M. & Fu, C. Y., et al., Progress in the study of the intervention effect and mechanism of exercise on depression. *China Sport Sci. Technol.* **56** (11), 13–24 (2020).
25. RADAK Z, MARTON O, NAGY E, *et al.* The complex role of physical exercise and reactive oxygen species on brain [J]. *J. of Sport and Health Sci.* **2**(2), 87-93 (2013).
26. Malik, A. A., Williams, C. A. & Weston, K. L., et al., Influence of personality and self-efficacy on perceptual responses during high-intensity interval exercise in adolescents. *J. Appl. Sport Psychol.* **33** (6), 590–608 (2021).
27. Voigt, D. C., Dillard, J. P. & Braddock, K. H., et al., Carver and White's (1994) BIS/BAS scales and their relationship to risky health behaviours. *Personality Individ. Differ.* **47** (2), 89–93 (2009).
28. Motl, R. W., McAuley, E. & Distefano, C., Is social desirability associated with self-reported physical activity? *Prev. Med.* **40** (6), 735–739 (2005).
29. Schmeichel, B. J., Crowell, A. & Harmon-Jones, E., Exercising self-control increases relative left frontal cortical activation. *Soc. Cognit. Affect. Neurosci.* **11** (2), 282–288 (2016).
30. Schneider, M. L. & Graham, D. J., Personality, physical fitness, and affective response to exercise among adolescents. *Med. Sci. Sports Exerc.* **41** (4), 947–955 (2009).
31. Ashdown-Franks, G. & Firth, R. C. J., et al., Exercise as medicine for mental and substance use disorders: A meta-review of the benefits for neuropsychiatric and cognitive outcomes. *Sports Med.* **50** (1), 151–170 (2020).
32. Zheng, W. J. & He, F., Sample size calculations for fact-finding missions. *Chin. Prevent. Med.* **32** (06), 647–648 (2020).
33. Liang, D. Q., Stress levels and their relationship with physical activity among university students. *Chin. Ment. Health J.* **01**, 5–6 (1994).
34. Ren, Y. & Li, M., Influence of physical exercise on social anxiety of left-behind children in rural areas in China: The mediator and moderator role of perceived social support. *J. Affect. Disord.* **266**, 223–229 (2020).
35. Heubeck, B. G., Wilkinson, R. B. & Cologon, J., A second look at Carver and White's (1994) BIS/BAS scales. *Personal. Individ. Differ.* **25** (4), 785–800 (1998).
36. Li, Y. Z., Zhang, Y. & Jiang, Y., et al., Reliability analysis of the Chinese version of the behavioural inhibition/activation system scale (BIS/BAS). *Chin. Ment. Health J.* **08**, 613–616 (2008).
37. Dear, B. F., Titov, N. & Sunderland, M., et al., Psychometric comparison of the generalized anxiety disorder scale-7 and the Penn State Worry Questionnaire for measuring response during treatment of generalised anxiety disorder. *Cogn. Behav. Ther.* **40** (3), 216–227 (2011).
38. Toussaint, A., Hüsing, P. & Gumz, A., et al., Sensitivity to change and minimal clinically important difference of the 7-item Generalized Anxiety Disorder Questionnaire (GAD-7). *J. Affect. Disorders* **265**, 395–401 (2020).
39. Spitzer, R. L., Kroenke, K. & Williams, J. B. W., et al., A brief measure for assessing generalized anxiety disorder: The GAD-7. *Arch. Intern. Med.* **166** (10), 1092–1097 (2006).
40. Plummer, F., Manea, L. & Trepel, D., et al., Screening for anxiety disorders with the GAD-7 and GAD-2: A systematic review and diagnostic metaanalysis. *Gen. Hosp. Psychiatry* **39**, 24–31 (2016).
41. Sousa, T. V., Viveiros, V. & Chai, M. V., et al., Reliability and validity of the Portuguese version of the Generalized Anxiety Disorder (GAD-7) scale. *Health Qual. Life Outcomes* **13**, 1–8 (2015).
42. Wang, Y., Chen, R. & Zhang, L., A reliability study of the Generalised Anxiety Scale-7 in Chinese general hospital inpatients. *J. Clin. Psychiatry* **28** (03), 168–171 (2018).
43. Cheng, Z. J. & Hou, W., *Structural equation modelling and its applications* (Educational Science Publishing House, 2006).
44. Dong, Z., Wang, P. & Xin, X., et al., The relationship between physical activity and trait anxiety in college students: The mediating role of executive function. *Front. Hum. Neurosci.* **16**, 1009540 (2022).
45. Arfaie, A., Safikhanlou, S. & Bakhshipour Roodsari, A., et al., Assessment of behavioral approach and behavioral inhibition systems in mood disorders. *Basic Clin. Neurosci.* **9** (4), 261–268 (2018).
46. Shawon, M. S. R., Hossain, F. B. & Hasan, M., et al., Gender differences in the prevalence of anxiety and depression and care seeking for mental health problems in Nepal: Analysis of nationally representative survey data. *Cambr. Prisms-Glob. Mental Health* **11**, 46 (2024).
47. Arcand, M., Bilodeau-Houle, A. & Juster, R.-P., et al., Sex and gender role differences on stress, depression, and anxiety symptoms in response to the COVID-19 pandemic over time. *Front. Psychol.* **14**, 1166154 (2023).
48. Xu, Z. & Du, J., A mental health informatics study on the mediating effect of the regulatory emotional self-efficacy. *Math. Biosci. Eng. MBE* **18** (3), 2775–2788 (2021).
49. LOU J, WU J, FENG M, *et al.* Exercise promotes angiogenesis by enhancing endothelial cell fatty acid utilization via liver-derived extracellular vesicle miR-122-5p [J]. *J. of Sport and Health Sci.* **11**(4), 495-508 (2022).
50. Li, L., Wang, P. & Li, S., et al., Canonical correlation analysis of depression and anxiety symptoms among college students and their relationship with physical activity. *Sci. Rep.* **13** (1), 11516 (2023).
51. Li, L., Wang, P. & Zhao, Q., et al., Latent profile analysis of depressive symptoms in college students and its relationship with physical activity. *J. Affect. Disord.* **351**, 364–371 (2024).
52. Strain, T., Flaxman, S. & Guthold, R., et al., National, regional, and global trends in insufficient physical activity among adults from 2000 to 2022: A pooled analysis of 507 population-based surveys with 5·7 million participants. *Lancet Glob. Health* **12** (8), e1232–e1243 (2024).
53. Xiang, M. Q., Tan, X. M. & Sun, J., et al., Relationship of physical activity with anxiety and depression symptoms in Chinese college students during the COVID-19 outbreak. *Front. Psychol.* **11**, 582436 (2020).
54. Firoozjah, M. H., Homayouni, A. & Shahrbanian, S., et al., Behavioral activation/inhibition systems and lifestyle as predictors of mental disorders in adolescent athletes during Covid19 pandemic. *BMC Public Health* **22** (1), 1444 (2022).
55. Ito, R., Kobayashi, N. & Yokoyama, S., et al., Interaction effects of behavioral inhibition system/behavioral activation system and cost/probability biases on social anxiety. *Front. Psychol.* **10**, 2536 (2019).
56. Sabo, A., Kueh, Y. C. & Arifin, W. N., et al., The validity and reliability of the Malay version of the social support for exercise and physical environment for physical activity scales. *PLoS ONE* **15** (9), e0239725 (2020).
57. Charles, S. & Carver, T. L. W., Behavioral inhibition, behavioral activation, and affective responses to impending reward and punishment: The BIS/BAS scales. *J. Personal. Soc. Psychol.* **67** (2), 319–333 (1994).
58. Caci, H., Deschaux, O. & Bayle, F. J., Psychometric properties of the French versions of the BIS/BAS scales and the SPSRQ. *Personal. Individ. Differ.* **42** (6), 987–998 (2007).
59. Matton, A., Goossens, L., & Braet, C., et al., Punishment and reward sensitivity: are naturally occurring clusters in these traits related to eating and weight problems in adolescents? *Eur. Eat. Disord. Rev.* **21** (3), 184–194 (2013).

60. Jung, W. H., Lee, T. Y. & Kim, M., et al., Sex differences in the behavioral inhibition system and ventromedial prefrontal cortex connectivity. *Soc. Cognit. Affect. Neurosci.* **17** (6), 571–578 (2022).
61. Verbeken, S., Braet, C. & Lammertyn, J., et al., How is reward sensitivity related to bodyweight in children? *Appetite* **58** (2), 478–483 (2012).
62. Guyer, A. E., McClure-Tone, E.B. & Shiffrin, N.D., et al., Probing the neural correlates of anticipated peer evaluation in adolescence. *Child Dev.* **80** (4), 1000–1015 (2009).
63. Shen, H., Du, X. & Fan, Y., et al., Interoceptive sensibility mediates anxiety changes induced by mindfulness-based Tai Chi Chuan movement intervention. *Mindfulness* **14** (7), 1662–1673 (2023).
64. Xu, M., Wang, J. & Jin, Z., et al., The behavioral inhibition system/behavioral activation system scales: Measurement invariance across gender in Chinese university students. *Front. Psychol.* **12**, 681753 (2021).
65. Connor, M., Hargreaves, E. A. & Scanlon, O.K., et al., The effect of acute exercise on state anxiety: A systematic review. *Sports* **11** (8), 145 (2023).

Author contributions

Wenli Wang: Conceptualization, Investigation, Methodology, Writing – Original Draft, Data Analysis, Project Administration.Hairong Liu: Technical Support, Language Editing, Final Proofreading.

Declarations

Competing interests

The authors declare no competing interests.

Additional information

Correspondence and requests for materials should be addressed to H.L.

Reprints and permissions information is available at www.nature.com/reprints.

Publisher's note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.