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RESEARCH

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Correlations between depressive symptoms, verbal working memory, and physical activity in university students: evidence based on resting EEG

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Abstract

Background Depressive symptoms are prevalent among university students and are closely correlated with verbal working memory. An increasing amount of evidence suggests that physical activity can mitigate depressive symptoms through multiple mechanisms. The objective of this study was to explore the correlations among depressive symptoms, verbal working memory, and physical activity in university students and to explore the potential correlations between these factors and EEG indicators.

Methods A case–control study design was employed to enroll 136 university students, and convenience samples were used to collect 5-minute resting EEG data with their eyes closed. Physical activity was evaluated using the Physical Activity Scale-3, depressive symptoms were assessed with the Beck Depression Inventory-II, and the N-back task was used to measure the accuracy rate and reaction time of verbal working memory. Pearson's correlation coefficient was calculated to assess the correlation between the variables, the PROCESS macro in SPSS (Model 4) was applied to analyze the mediating role of verbal working memory in the correlation between physical activity and depressive symptoms, and the bootstrap method was used to calculate the mediating effect.

Results The results showed that the verbal working memory reaction time and physical activity scores of university students with depressive symptoms were significantly different from those of university students without depressive symptoms ($P < 0.05$), but no difference was found in the accuracy rate of verbal working memory ($t = 0.580$, $P > 0.05$). Physical activity was negatively correlated with depressive symptom scores (r=-369, $P < 0.05$) and with the reaction time of verbal working memory (r=-0.334, $P < 0.05$). Mediation analyses indicated that the verbal working memory reaction time partially mediated (β = -0.039, 95% CI = -0.096 to -0.001) the correlation between physical activity and depressive symptoms in university students. EEG indicators in the frontal regions of the brain, including beta2 power values for (FP1, FP2) and delta power values for (F3, F4) and (F7, F8), were negatively correlated with depressive

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symptom scores and verbal working memory reaction time and positively correlated with the level of physical activity ($P < 0.05$).

Conclusions Differences in physical activity and VWM reaction time between university students with depressive symptoms and those without depressive symptoms. Three variables, depressive symptom scores, VWM, and physical activity, had mutually related EEG indicators, which may provide a useful addition to the clinical identification and targeting of interventions in the population with depressive symptoms. Verbal working memory partially mediated the relationship between physical activity and depressive symptoms, but the mediating path coefficient accounted for a low percentage.

Clinical trial number Not applicable.

Keywords Physical activity, Depressive symptoms, Verbal working memory, EEG

Background

The World Health Organization (WHO) has explicitly noted that depression is the third leading contributor to the global disease burden and predicted that by 2030, depression is likely to be the leading cause of the global disease burden [1]. Depressive symptoms are considered the transitional phase leading to the onset of depression, which features a persistent low mood, loss of interest and energy, impaired cognitive functioning, and, in severe cases, self-harming or suicidal thoughts or behaviors [2, 3]. In university students, the incidence of depressive symptoms is high due to intense academic competition and escalating life pressures [4, 5]. A meta-analysis of Chinese university students revealed that the prevalence of depressive symptoms was as high as 24.4% [6]. In addition, patients with depressive symptoms have impaired working memory and long-term memory, and these symptoms are further exacerbated by recurrent episodes of depressive symptoms [7, 8].

Working memory, an integral part of cognitive functioning, is strongly associated with the onset and development of depressive symptoms [9]. Depressive symptoms can impair working memory, and in turn, the working memory impairment may exacerbate depressive symptoms [10]. In verbal working memory (VWM), patients with depressive symptoms have difficulty updating negative information and have deficits in processing positive information [11]. Individuals with depressive symptoms often show slower responses, higher error rates, and difficulties in switching tasks and updating information when performing VWM tasks [12]. Several reviews have shown that patients with depressive symptoms perform worse than control individuals do in completing VWM tasks [7, 13]. Imaging studies have revealed that the cortex and cingulate gyri are more active in patients with clinical depressive symptoms performing the N-back task than in control individuals [14], and abnormalities in neural circuits supporting working memory may be a physiological marker of depressive symptoms [15], whereas decreases in VWM may lead to more severe depressive symptoms.

As an effective means of improving cognitive function, physical activity has attracted a great deal of attention from researchers in recent years [16, 17]. Studies have shown a certain correlation between physical activity levels and the risk of depressive symptoms, including a positive correlation between lower levels of physical activity and a greater risk of depressive symptoms in university students [18–20]. Exercise increases neuroplasticity, reduces oxidative stress, and alters neuroendocrine levels, thus reducing depressive symptoms [21, 22]. A positive correlation has been observed between physical activity and improved working memory function [23, 24], which may be linked to functional changes in executive control circuits in the frontal lobes among patients [25]. Patients with depressive symptoms exhibit persistent abnormal functioning of calcium signaling circuits from the limbic to the subcortical regions during VWM processing [26], and in these patients, physical activity may improve the performance of the activation system in the frontoparietal network [27].

An electroencephalogram (EEG) is an external reflection of the electrophysiological activity of brain neurons and has the strengths of being simple, convenient and noninvasive [28, 29]; an EEG can provide a quantitative basis for the effects of exercise on alleviating university students' depressive symptoms and improving working memory [30]. The parietal cortex is involved in information storage [31, 32], and the occipital cortex is involved in visual attention [33]. Certain specificities in the EEG signals of people suffering from depressive symptoms have been observed, such as lower power of the delta wave during sleep [34] and lateralization of the theta and alpha waves in the left and right brain regions [35–37]. Lower frequency bands in the EEG (e.g., beta and delta bands) are strongly associated with a decline in working memory [38–40], and exercise induces an immediate postexercise cortisol elevation, causing brain oscillatory activity and EEG alpha asymmetry and mitigating negative emotions [41].

A review of the previous literature revealed that physical activity is strongly correlated with working memory and depressive symptoms [42–44]. However, when the correlation between VWM and depressive symptoms in university students is explored, we find that numerous research results are controversial—some studies find that the accuracy rate better reflects VWM ability [45], whereas other studies suggest that reaction time is a more valid indicator [46, 47]. These controversies need further validation in future generations. Furthermore, the selection of VWM indicators has shown inconsistency when exploring the correlation between physical activity and depressive symptoms, with some studies focusing on changes in the accuracy rate [45, 48] and others emphasizing reductions in reaction time, as it reflects increased efficiency in cognitive processing [49, 50]. These studies provide valuable insights, but they are all generally unconvincing. The intervention of EEG offers the possibility of providing insights into this issue. EEG technology provides real-time information on brain activity, which is critical for understanding the interconnections among physical activity, depressive symptoms, and VWM. Based on this premise, a case-control research paradigm was selected for this study, which was intended to address the following research questions: (1) Do differences exist in the variables of VWM and physical activity between university students with depressive symptoms and those without depressive symptoms? (2) Are the three variables, namely, depressive symptom scores, VWM, and physical activity, correlated and does VWM mediate the correlation between physical activity and depressive symptom scores? (3) Which variables, depressive symptom scores, VWM or physical activity, of university students are related to EEG indicators?

The team intends to provide directions and ideas for clinical identification and targeted exercise interventions for people with depressive symptoms, as well as to provide references for researchers through this study.

Research subjects and methods

Research subjects

The overall sample size was estimated using G*Power 3.1 software, and this study was a case-control study. For the purpose of this study, the ratio of students in the group with depressive symptoms to the group without depressive symptoms was set at 1:1, the t test was selected, the statistical test was selected as "Means: Difference between two independent means (two groups)", the medium effect size was referenced (0.5) [51], the alpha value was 0.05, the test efficacy was set at 0.8, and the required sample size for each group was 64 persons. Each group included a minimum of 67 persons, accounting for a 5% attrition rate.

A total of 136 university students were recruited through posters, health education lectures, and online recruitment in a university town in Songjiang District, Shanghai, using a case-control study paradigm and convenience sampling.

The subjects were required to visit the laboratory twice. At the first visit, the subjects were informed of the purpose and content of the study, signed an informed consent form and completed a sociodemographic questionnaire, the Beck Depression Inventory-II, and the Physical Activity Scale-3. At the second visit, the subjects who met the criteria underwent resting EEG acquisition and VWM testing. A flowchart of the subject recruitment process is shown in Fig. 1.

The inclusion criteria were as follows: (1) registered university student; (2) aged between 17 and 25 years old; (3) right-handed; (4) Beck Depression Inventory scores ranged from 14 to 28 in the group with depressive

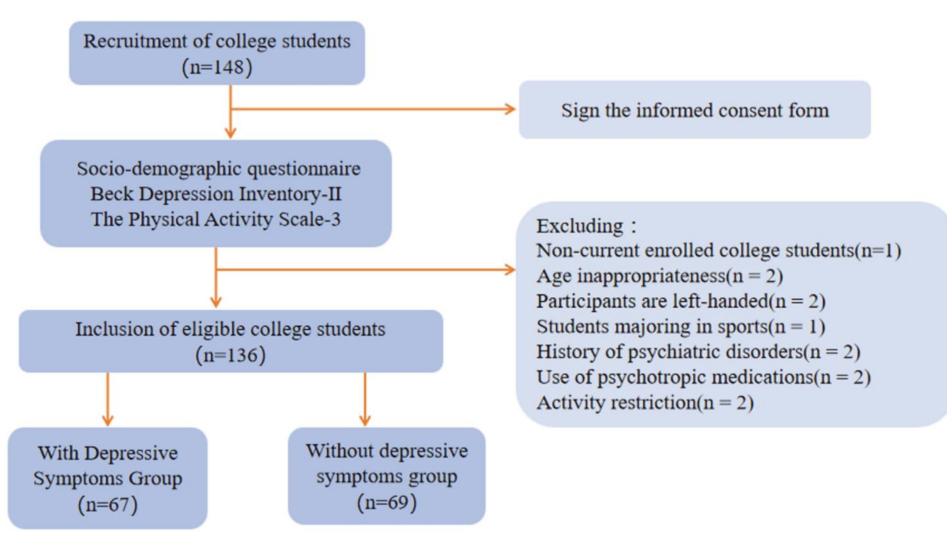

Fig. 1 Flowchart of subject recruitment

symptoms and were < 14 in the group without depressive symptoms.

The exclusion criteria were as follows: (1) students majoring in sports; (2) those with a history of psychiatric disorders; (3) past or current use of psychotropic medications; (4) and activity restrictions.

This study was approved by the Ethics Committee of Shanghai University of Sport (Ethical Approval No. 102772024RT108). All the participants were informed of the measurement procedures and potential risks prior to the experiment and provided written informed consent.

Test procedure

The testing was conducted from September to December 2023, with all the sessions held between 13:30 and 16:30 (including EEG signal collection and questionnaire administration). The testing procedure is shown in Fig. 2. The participants were instructed to avoid intense exercise and refrain from consuming caffeinated or alcoholic beverages within 24 h prior to testing. All the subjects provided informed consent and participated in the experiment voluntarily.

Questionnaire survey

Sociodemographic questionnaire A sociodemographic questionnaire was designed to collect basic information about the subjects, including sex, age (years), height (meters), weight (kg), residence registration (urban/rural), social participation, smoking habits (≥ 1 cigarette per day for 6 consecutive or cumulative months) and alcohol consumption habits (≥ once per week for the past year).

Beck depression Inventory-II (BDI-II) The scale includes 21 items, each rated on a 0 to 3 point scale. The total score is the sum of all the items, with scores ranging from 0 to 63 [52]. Based on the classifications provided by the scale, scores of 0–13 indicate no depression, 14–19 indicate mild depression, 20–28 indicate moderate depression, and 29–63 indicate severe depression. The Cronbach's α coefficient for this questionnaire in the current study was 0.86 [53].

Physical activity Scale-3 (PARS-3) The scale was developed by Koshio Hashimoto, and this study used the Chinese version revised by Liang Deqing et al. [54]. The scale mainly reflects the physical activity of individuals in the last month, including intensity, duration, and frequency. Intensity and frequency are divided into 5 grades and scored from 15 points, and duration is divided into 5 grades and scored from 04 points. The formula for calculating the amount of physical activity is intensity × duration × frequency, and the score range is 0–100 points. The Cronbach's alpha coefficient of the questionnaire in this study was 0.82 [55].

Verbal working memory

This study was designed with the classic "N-back" verbal working memory task paradigm, and the VWM task indicators included reaction time and accuracy rate, as shown in Fig. 3. The specific task design was as follows: the N-back task used MATLAB software. The participants completed the experiment by tapping on the keyboards of computers. The screen randomly displayed eight different uppercase letters—B, D, H, K, M, P, S, and Y. Participants were instructed to remember the letters themselves, disregarding their spatial position. A total of 76 trials were performed, including 10 practice trials and 66 formal trials. Only after achieving a 75% accuracy rate in the 10 practice trials could the participants begin the formal trials. Otherwise, they needed to press the "Q" key to repeat the practice, with a maximum of three extra practice attempts. After the practice trials, the participants were instructed to rest for 30 s before pressing the "Enter" key to start the formal trials. The formal trials consisted of 66 trials with the following sequence: a fixation point "+" was presented for 3000 ms on the screen, followed by an image containing one letter for 2000 ms, with a 1000 ms interstimulus interval. The subjects were asked to remember the letter itself, ignoring its spatial position. If the current letter was identical to the Nth letter prior to it, they pressed the "L" key; if not, they pressed the "F" key. The ratio of stimulus match to nonmatch trials was 1:1.

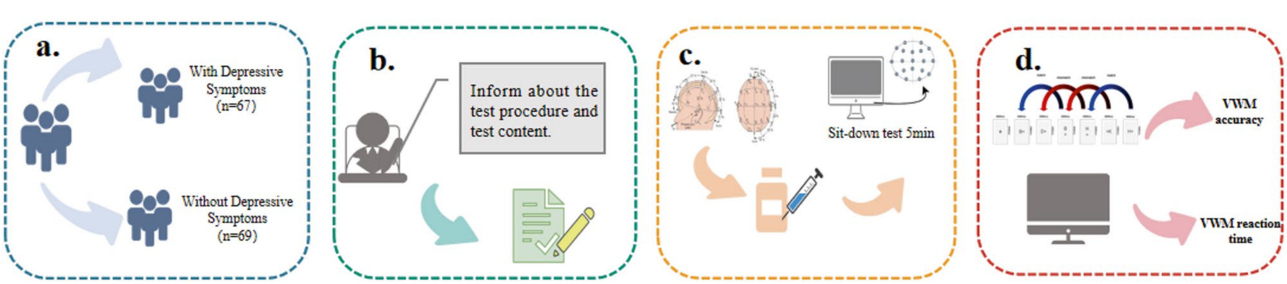

Fig. 2 Testing flowchart

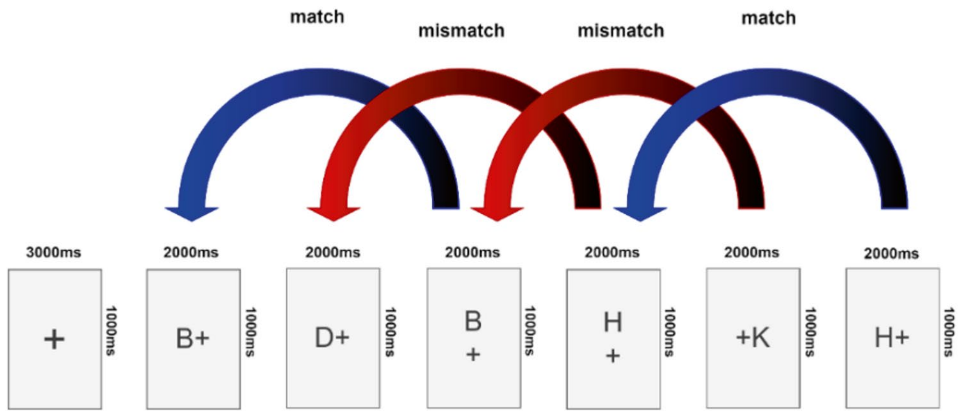

Fig. 3 Diagram of the VWM task (N-back)

EEG signal acquisition and data processing

EEG signals were recorded using an EEG device (NCERP-190012) produced by Nuo Cheng China (NCC) Electrophysiology Co., Ltd., which was equipped with a preamplifier and employed 16 unipolar leads. The sampling rate was set at 500 Hz, with a high-pass filter at 0.3 Hz, a low-pass filter at 30 Hz, and a notch filter at 50 Hz. Electrodes were applied according to the 10/20 system recommended by the International Society for Electroencephalography, with lead electrodes placed at the following sites: left frontal (Fp1), right frontal (Fp2), left posterior frontal (F3), right posterior frontal (F4), left central (C3), right central (C4), left parietal (P3), right parietal (P4), left anterior (F7), right anterior (F8), left occipital (O1), right occipital (O2), left temporal (T3), right temporal (T4), left posterior temporal (T5), and right posterior temporal (T6). The ground electrode was positioned at the frontal midline, and reference electrodes were placed on both earlobes (A1 and A2). During testing, the participants were asked to remain awake and relax their bodies while they were resting, with their hands naturally positioned at their sides and their eyes closed. The participants were instructed to avoid clenching their teeth or swallowing saliva. EEG signals were collected for five minutes while the participants sat quietly.

EEG signals were divided into the following frequency bands by the recording equipment: delta (1–4 Hz), theta (4–8 Hz), alpha1 (8–10.5 Hz), alpha2 (10.5–13 Hz), beta1 (13–20 Hz), and beta2 (20–30 Hz). The frequency ranges were defined as left-closed, right-open intervals, with the boundary values assigned to the higher frequency band. Data segments with clear artifacts, such as eye movement artifacts, were removed using specialized software. Each lead signal was categorized by brain region, including the orbital frontal (Fp1, Fp2), anterior frontal (F3, F4), lateral frontal (F7, F8), central (C3, C4), parietal (P3, P4), occipital (O1, O2), temporal (T3, T4), and posterior temporal (T5, T6) regions. The EEG power value for each brain region was calculated as P_left + P_right.

Statistical analysis

The data were statistically analyzed using SPSS 26.0 software. Quantitative data were assessed for normality by the Shapiro−Wilk test, normally distributed data were described as means ± standard deviations, and independent samples t tests were used to compare intergroup differences between university students with and without depressive symptoms. For categorical data, frequencies (percentages) were used to describe the data, and chi-squared tests were applied for intergroup comparisons. Correlations among depressive symptom scores, physical activity, VWM reaction time, and EEG indicators in university students with depressive symptoms were analyzed by Pearson's correlation analysis. Mediation analyses were conducted using the PROCESS macro (Model 4) of SPSS provided by Hayes [56] to examine the mediating role of the VWM reaction time in the correlation between physical activity and depressive symptom scores. Mediating effects were tested using the bootstrap method with 5000 resamples to generate confidence intervals. All the statistical analyses were performed using a two-tailed test, and the significance level was set at $\alpha = 0.05$ to indicate the significance of the statistical results.

Results

Sociodemographic characteristics of the subjects

A total of 136 university students, with an average age of 19.81 ± 1.285 years, height of 1.68 ± 0.075 m, and weight of 62.40 ± 14.666 kg, participated in this study. A total of 3.7% of them had smoking habits, and 22.1% had drinking habits. The average physical activity score was 16.65 ± 18.056 points, the accuracy rate of the VWM task was 0.88 ± 0.069, and the reaction time was 1.04 ± 0.142. University students with depressive symptoms and those without depressive symptoms did not present significant differences in age, sex, height, weight, household, smoking, or alcohol consumption indicators (all $P > 0.05$), but the difference in social participation was statistically significant ($t = 15.114$, $P < 0.05$), as university students with

Table 1 Sociodemographic characteristics of the subjects

Variable	Overall	Without Depressive Symptoms	With Depressive Symptoms	t/χ²	*P*
	***N*=136**	***N*=69**	***N*=67**		
Age (years old)	19.81 ± 1.285	19.80 ± 1.389	19.82 ± 1.180	-0.108	0.915
Sex (%)				0.727	0.394
Female	51.5	55.1	47.8		
Male	48.5	44.9	52.2		
Height (m)	1.68 ± 0.075	1.69 ± 0.075	1.67 ± 0.075	0.898	0.371
Weight (kg)	62.40 ± 14.666	60.68 ± 11.540	64.16 ± 17.220	-1.389	0.167
Registered residence (%)				3.100	0.078
Urban	8.8	13.0	4.5		
Rural	91.2	87.0	95.5		
Drinking habit (%)				0.255	0.614
Yes	22.1	20.3	23.9		
No	77.9	79.7	76.1		
Smoking habit (%)				0.178	0.673
Yes	3.7	4.3	3.0		
No	96.3	95.7	97.0		
Social participation (%)				15.114	0.002
None	25.0	14.5	35.8		
1–3 times/week	70.6	82.6	58.2		
4–6 times/week	1.5	2.9	0		
Every day	2.9	0	6.0		
Physical activity	16.65 ± 18.056	23.23 ± 21.742	9.88 ± 9.382	4.673	< 0.001
VWM accuracy rate (%)	0.88 ± 0.069	0.88 ± 0.060	0.87 ± 0.078	0.580	0.563
VWM reaction time (s)	1.04 ± 0.142	1.01 ± 0.147	1.08 ± 0.128	-2.877	0.005

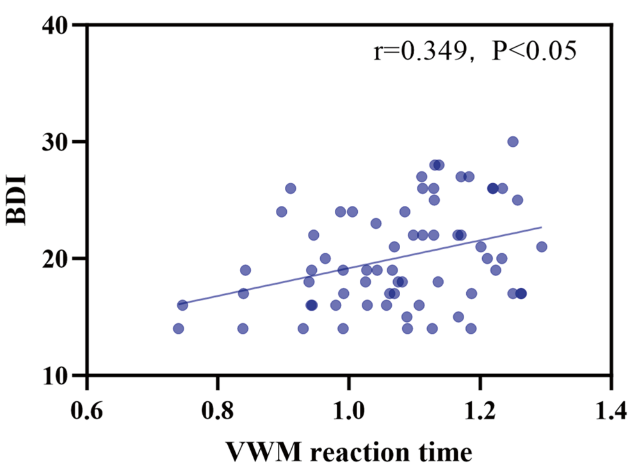

Fig. 4 Correlation between depressive symptom scores and VWM (reaction time) Note: BDI indicates the depressive symptom score; VWM is verbal working memory

depressive symptoms showed lower social participation, as shown in Table 1.

Independent samples t tests were used to analyze differences in VWM and physical activity between university students with depressive symptoms and those without depressive symptoms. The results revealed that the average reaction time of university students with depressive symptoms was 1.08 s, and the average physical activity score was 9.88. Compared with university students without depressive symptoms, university students with depressive symptoms had less physical activity, the reaction time of VWM was shorter, and the differences were significant (both $P < 0.05$). The average accuracy rate of VWM was 87%, which did not differ significantly ($t = 0.580$, $P > 0.05$). This result suggests that physical activity and the VWM reaction time may be potential factors contributing to depressive symptoms.

Correlations between depressive symptom scores and VWM (reaction time) in university students with depressive symptoms

A correlation analysis was conducted to examine the correlation between depressive symptom scores and the VWM reaction time. As shown in Fig. 4, depressive symptom scores were positively correlated with the VWM reaction time ($r = 0.349$, $P < 0.05$). The higher the depressive symptom score was, the slower the VWM reaction time was.

Correlations among physical activity, depressive symptom scores and VWM (reaction time) in university students with depressive symptoms

After controlling for confounding factors, Pearson's correlation analysis was conducted to examine the correlations among physical activity, depressive symptom scores and VWM (reaction time) in university students with depressive symptoms. As shown in Fig. 5, physical

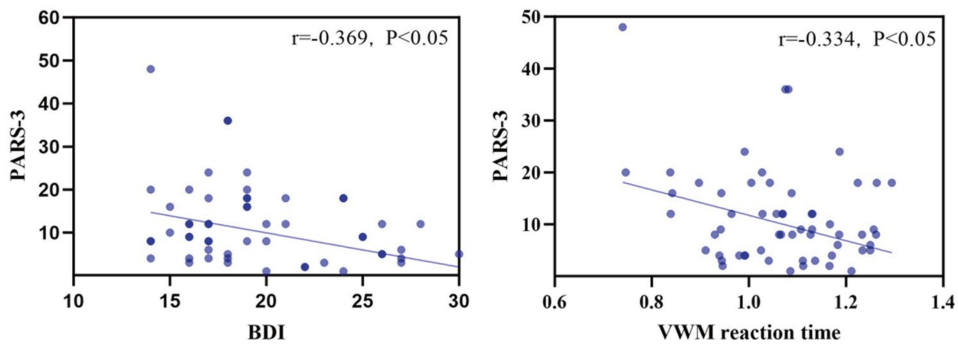

Fig. 5 Correlations among physical activity, depressive symptom scores and VWM (reaction time) Note: PARS-3 indicates physical activity; BDI indicates depressive symptom scores; VWM indicates verbal working memory

Table 2 Regression analysis of the mediating role of VWM (reaction time) between physical activity and depressive symptoms

Outcome variable	Predictor variable	Overall fit index			Significance of the regression coefficients		
		R	R^2	F	β	t	*P*
VWM reaction time	Physical activity	0.3338	0.1114	8.1490	-0.0046	-2.8547	0.0058
Depressive symptoms	Physical activity	0.3688	0.1360	10.2353	-0.1713	-3.1993	0.0021
Depressive symptoms	Physical activity	0.4398	0.1935	7.6760	-0.1319	-2.3847	0.0201
	VWM reaction time				8.6616	2.1347	0.0366

Table 3 Analysis of total effects, direct effects, and mediating effects

Type of effect	Effect size	se	LLCI	ULCI	Effect proportion
Total effect	-0.171	0.054	-0.278	-0.064	100%
Direct effect	-0.132	0.056	-0.242	-0.021	77.19%
Mediating effect	-0.039	0.025	-0.096	-0.001	22.81%

activity was negatively correlated with the depressive symptom score (r = -0.369, $P<0.05$) and VWM reaction time (r = -0.334, $P<0.05$). These findings indicate that the higher the physical activity score is in university students with depressive symptoms, the lower the depressive symptom score and the faster the VWM reaction time.

The mediating role of VWM (reaction time) in the correlation between physical activity and depressive symptom scores

This study considered the VWM reaction time as a mediator in the structural equation model to study the potential mechanism underlying the effect of physical activity on depressive symptoms. The PROCESS macro of SPSS (Model 4) was adopted to conduct regression analyses of the mediating effects. The test results in Table 2 showed that physical activity negatively predicted the VWM reaction time (β =-0.0046, $P<0.01$). In addition, physical activity negatively predicted depressive symptoms (β = -0.1319, $P<0.05$), and the VWM reaction time positively predicted depressive symptoms ($\beta = 8.6616$, $P<0.05$).

A bootstrap approach was used to analyze how the VWM reaction time mediated the correlation between physical activity and depressive symptoms. According to Table 3, the bootstrap 95% confidence intervals for the mediating effects of physical activity on depressive symptoms and VWM reaction time did not include 0. The direct effect of physical activity on depressive symptoms was – 0.132 (95% CI = -0.242 to -0.021), which accounted for 77.19% of the total effect, whereas the effect mediated by VWM was – 0.039 (95% CI = -0.096 to -0.001), which accounted for 22.80% of the total effect.

As shown in Fig. 6, these results suggested that physical activity reduced depressive symptoms through both direct and indirect pathways (by improving the VWM reaction time) and that physical activity could benefit patients with depressive symptoms.

Selection of EEG indicators in relation to depressive symptom scores and VWM (reaction time)

Pearson's correlation analysis was used to explore the correlations between EEG indicators, depressive symptoms and the VWM reaction time. The results are shown in Fig. 7, where beta1 and beta2 power values in frontal regions (FP1, FP2), delta power values in frontal regions (F3, F4), and frontal regions (F7, F8) were the EEG indicators that were associated with depressive symptoms and the VWM reaction time. The more obvious the depressive symptoms and the longer the reaction time of university students with depressive symptoms, the lower the EEG activity on these EEG indicators, especially in the frontal and central regions. Those indicators that were correlated with each other were referred to as EEG-specific indicators in this paper.

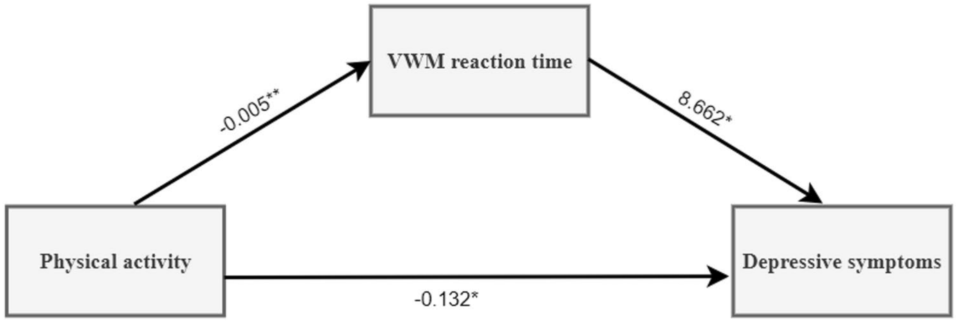

Fig. 6 The mediating role of the VWM reaction time in the correlation between physical activity and depressive symptoms

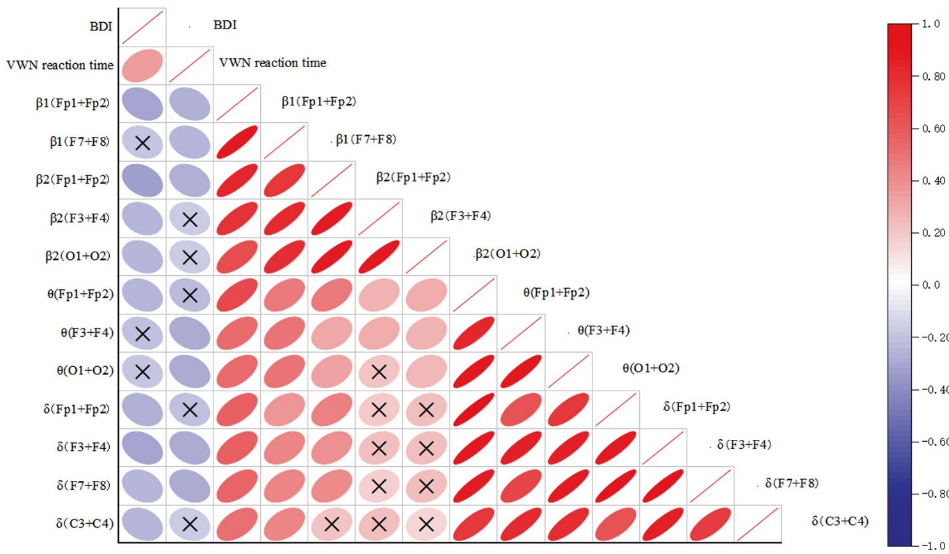

Fig. 7 Correlations between depressive symptom scores, VWM (reaction time) and EEG indicators. Note: The figure only presents the EEG indicators suggesting a correlation between depressive symptom scores and the VWM reaction time; VWN indicates verbal working memory; and BDI indicates the depressive symptom score

Correlations between EEG-specific indicators and physical activity in university students with depressive symptoms

We calculated Pearson's correlation coefficients to explore the correlations between physical activity and EEG-specific indicators. As shown in Fig. 8, physical activity was positively correlated with beta2 power values in frontal regions (FP1, FP2), delta power values in frontal regions (F3, F4), and frontal regions (F7, F8) ($P < 0.05$). These results suggest that physical activity is strongly correlated with neurophysiological activity—the higher the level of physical activity is, the stronger the activation of relevant EEG indicators.

Discussion

The results of the study showed that the physical activity scores of university students with depressive symptoms differ from those of university students without depressive symptoms. A negative correlation was observed between the physical activity score and depressive symptom score, which is consistent with the findings of previous studies. Inadequate physical activity has been found to be a risk factor for depressive symptoms in university students [57], and increasing the level of physical activity in university students can effectively regulate and improve depression [58, 59]. In addition, long-term physical activity can lead to positive self-evaluations in individuals, increasing positive emotions and decreasing negative emotions such as depression [60, 61]. The reason for this improvement may be that physical activity reduces depressive symptoms by improving physiological mechanisms such as enhancing neuronal plasticity, increasing the levels of pentraxin and brain-derived neurotrophic factor, promoting the regulation of the hypothalamic–pituitary–adrenocortical (HPA) axis, and suppressing inflammatory responses [62].

We found that the VWM reaction time partially mediated the relationship between physical activity and depressive symptoms and that physical activity was associated with depressive symptoms; we also identified a possible indirect link to depressive symptoms through

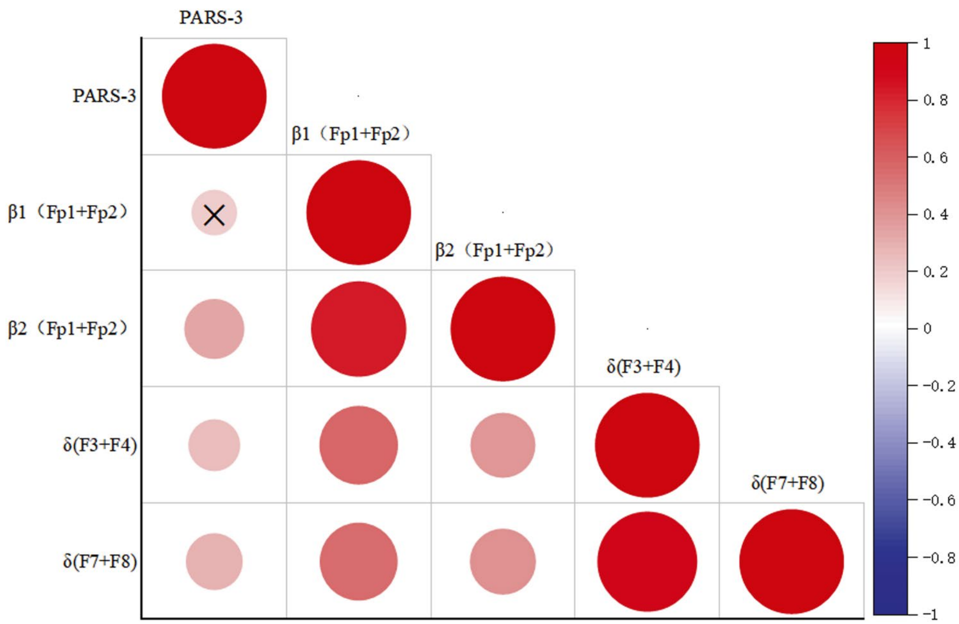

Fig. 8 Correlations between EEG-specific indicators and physical activity. Note: PARS-3 indicates the physical activity score

the VWM reaction time. Physical activity increases blood circulation in the brain and enhances neuroplasticity, which improves an individual's VWM [63], and individuals who participate in physical activity on a regular basis perform better at processing and storing information [64]. Exercise may improve VWM by increasing brain-derived neurotrophic factor (BDNF) levels and the hippocampal volume [65, 66], thus reducing depressive symptoms.

We found that the brain regions showing EEG indicators related to depressive symptom scores and VWM (reaction time) were beta2 waves in frontal regions (FP1, FP2) and delta waves in (F3, F4) and (F7, F8). Delta-band hyperactivity in patients with depressive symptoms is a compensatory mechanism for depressive symptom-induced cortical deficits, which can be mediated through the modulation of cognitive functions [67]. With increasing exercise, beta-wave power values increase, which may be related to elevated attention demands and arousal levels after exercise [68] and is usually associated with an increase in beta-wave power values [69]. With increasing amounts of physical activity, the activation of beta and delta power values increased. This finding suggests some common neurophysiological basis between the effects of physical activity on depressive symptoms and VWM: the greater the level of physical activity, the greater the degree of activation of activity in these brain regions.

We also found that university students with depressive symptoms may have impaired VWM and showed longer reaction times when completing the "N-back" VWM task; thus, the reaction time may be a major indicator of impaired VWM in university students with depressive symptoms. This result is inconsistent with previous studies in which the "accuracy rate" was the main indicator [45]. Patients with depressive symptoms often experience abnormal activation of the frontal lobes when performing working memory tasks [70, 71], which may be the main reason for the prolonged reaction time. Furthermore, differences in samples, research methodologies, and external factors may have led to the inconsistent results.

Limitations of this paper: The sample size of this study was not large enough, which may affect the precision of the statistics of the correlation coefficients and the estimation of the mediating path coefficients. Future studies should increase the sample size to better validate and extend the results of this study. This study used an observational research design, and future studies should utilize a longitudinal or experimental design with long-term follow-up to investigate the causal relationships among physical activity, depressive symptoms and VWM. Social participation factors were not adequately considered in this study, which may impact the results, and research on social participation variables could be considered when the same group is explored in the future. In addition, future studies could incorporate questionnaires, EEG measurements, and other neuroimaging techniques, such as fMRI, to more fully understand the effects of physical activity on brain structure and function and how these changes may be associated with depressive symptoms and VWM.

Conclusions

Differences in physical activity and the VWM reaction time were observed between university students with depressive symptoms and those without depressive symptoms. Three variables, depressive symptom scores, VWM, and physical activity, have mutually related EEG indicators, which may provide a useful addition to the clinical identification of and targeting of interventions in the population with depressive symptoms. Verbal working memory partially mediated the relationship between physical activity and depressive symptoms, but the mediating path coefficient accounted for a low percentage.

Author contributions

Yuxi Ren (First Author): Conceptualization, Methodology, Software, Investigation, Formal Analysis, Writing - Original Draft; Shufan Li: Data Curation, Software, Writing - Original Draft; Shuqi Jia: Visualization, Investigation, Resources, Validation; Xing Wang: Visualization, Writing - Review & Editing; Haiyan Wen (Corresponding Author): Conceptualization, Funding Acquisition, Resources, Supervision, Writing - Review & Editing.

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Data availability

Data is provided within the manuscript or supplementary information files.

Declarations

Ethical approval and consent to participate

For experiments involving human participants, informed consent was obtained from all the subjects (all adults) in this study. Our study was approved by the Ethics Committee of Shanghai University of Sport (102772024RT108). All methods were performed in accordance with relevant guidelines and regulations.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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References

1. Malhi GS, Mann JJ, Depression. Lancet. 2018;392(10161):2299–312.
2. LeMoult J, Gotlib IH, Depression. A cognitive perspective. Clin Psychol Rev. 2019;69:51–66.
3. Thapar A, Eyre O, Patel V, Brent D. Depression in young people. Lancet. 2022;400(10352):617–31.
4. Taghani A, Razavi MR. The effect of metacognitive skills training of study strategies on academic self-efficacy and academic engagement and performance of female students in Taybad. Curr Psychol. 2022;41(12):8784–92.
5. Fernandes MSV, Mendonça CR, da Silva TMV, Noll PRS, de Abreu LC, Noll M. Relationship between depression and quality of life among students: a systematic review and meta-analysis. Sci Rep. 2023;13(1):6715.
6. Akhtar P, Ma L, Waqas A, Naveed S, Li Y, Rahman A, et al. Prevalence of depression among university students in low and middle income countries (LMICs): a systematic review and meta-analysis. J Affect Disord. 2020;274:911–9.
7. Semkovska M, Quinlivan L, O'Grady T, Johnson R, Collins A, O'Connor J, et al. Cognitive function following a major depressive episode: a systematic review and meta-analysis. Lancet Psychiatry. 2019;6(10):851–61.
8. Hasselbalch B, Knorr U, Hasselbalch S, Gade A, Kessing L. The cumulative load of depressive illness is associated with cognitive function in the remitted state of unipolar depressive disorder. Eur Psychiatry. 2013;28(6):349–55.
9. Rayner G, Jackson G, Wilson S. Cognition-related brain networks underpin the symptoms of unipolar depression: evidence from a systematic review. Neurosci Biobehav Rev. 2016;61:53–65.
10. Rutherford AV, McDougle SD, Joormann J. Don't [ruminate], be happy: A cognitive perspective linking depression and anhedonia. Clin Psychol Rev. 2023;101:102255.
11. Chen Z, Dou Z, Xu H, Wang Z, Zeng S, Yang X et al. Decomposing working memory in recurrent major depression: impaired encoding and limited maintenance Immune-to-Encoding constraint. Brain Sci. 2022;13(1).
12. Nikolin S, Tan YY, Schwaab A, Moffa A, Loo CK, Martin D. An investigation of working memory deficits in depression using the n-back task: A systematic review and meta-analysis. J Affect Disord. 2021;284:1–8.
13. Schumacher A, Campisi SC, Khalfan AF, Merriman K, Williams TS, Korczak DJ. Cognitive functioning in children and adolescents with depression: A systematic review and meta-analysis. Eur Neuropsychopharmacol. 2024;79:49–58.
14. Harvey PO, Fossati P, Pochon JB, Levy R, Lebastard G, Lehéricy S, et al. Cognitive control and brain resources in major depression: an fMRI study using the n-back task. NeuroImage. 2005;26(3):860–9.
15. Walsh ND, Williams SC, Brammer MJ, Bullmore ET, Kim J, Suckling J, et al. A longitudinal functional magnetic resonance imaging study of verbal working memory in depression after antidepressant therapy. Biol Psychiatry. 2007;62(11):1236–43.
16. Hillman CH, Erickson KI, Kramer AF. Be smart, exercise your heart: exercise effects on brain and cognition. Nat Rev Neurosci. 2008;9(1):58–65.
17. Kramer AF, Erickson KI. Capitalizing on cortical plasticity: influence of physical activity on cognition and brain function. Trends Cogn Sci. 2007;11(8):342–8.
18. Dugan SA, Bromberger JT, Segawa E, Avery E, Sternfeld B. Association between physical activity and depressive symptoms: midlife women in SWAN. Med Sci Sports Exerc. 2015;47(2):335–42.
19. Giuli C, Papa R, Bevilacqua R, Felici E, Gagliardi C, Marcellini F, et al. Correlates of perceived health related quality of life in obese, overweight and normal weight older adults: an observational study. BMC Public Health. 2014;14:35.
20. Kremer P, Elshaug C, Leslie E, Toumbourou JW, Patton GC, Williams J. Physical activity, leisure-time screen use and depression among children and young adolescents. J Sci Med Sport. 2014;17(2):183–7.
21. Bellón J. Exercise for the treatment of depression. BMJ (Clinical Res ed). 2024;384:q320.
22. Fabiano NT. The effect of exercise on suicide in people with depression. BMJ (Clinical Res ed). 2024;384:q609.
23. Scott SP, MJ DES, Koehler K, Petkus DL, Murray-Kolb LE. Cardiorespiratory fitness is associated with better executive function in young women. Med Sci Sports Exerc. 2016;48(10):1994–2002.
24. McNeill J, Howard SJ, Vella SA, Cliff DP. Compliance with the 24-Hour movement guidelines for the early years: Cross-sectional and longitudinal associations with executive function and psychosocial health in preschool children. J Sci Med Sport. 2020;23(9):846–53.
25. Hack LM, Tozzi L, Zenteno S, Olmsted AM, Hilton R, Jubeir J, et al. A cognitive biotype of depression linking symptoms, behavior measures, neural circuits, and differential treatment outcomes: A prespecified secondary analysis of a randomized clinical trial. JAMA Netw Open. 2023;6(6):e2318411–e.
26. Liu J, Mo J-W, Wang X, An Z, Zhang S, Zhang C-Y, et al. Astrocyte dysfunction drives abnormal resting-state functional connectivity in depression. Sci Adv. 2022;8(46):eabo2098.
27. Dietrich A, Audiffren M. The reticular-activating hypofrontality (RAH) model of acute exercise. Neurosci Biobehav Rev. 2011;35(6):1305–25.
28. Murphy M, Whitton AE, Deccy S, Ironside ML, Rutherford A, Beltzer M, et al. Abnormalities in electroencephalographic microstates are state and trait markers of major depressive disorder. Neuropsychopharmacology: Official Publication Am Coll Neuropsychopharmacol. 2020;45(12):2030–7.
29. Xue R, Li X, Deng W, Liang C, Chen M, Chen J et al. Shared and distinct electroencephalogram microstate abnormalities across schizophrenia, bipolar disorder, and depression. Psychol Med. 2024:1–8.

30. Li J, Cao D, Li W, Sarnthein J, Jiang T. Re-evaluating human MTL in working memory: insights from intracranial recordings. Trends Cogn Sci. 2024.
31. Brodt S, Gais S, Beck J, Erb M, Scheffler K, Schönauer M. Fast track to the neocortex: A memory engram in the posterior parietal cortex. Volume 362. New York, NY: Science; 2018. pp. 1045–8. 6418.
32. Su K, Huang Z, Li Q, Fan M, Li T, Yin D. Dissociable functional responses along the posterior-anterior gradient of the frontal and parietal cortices revealed by parametric working memory and training. Brain Struct Function. 2024;229(7):1681–96.
33. Alekseichuk I, Diers K, Paulus W, Antal A. Transcranial electrical stimulation of the occipital cortex during visual perception modifies the magnitude of BOLD activity: a combined tES–fMRI approach. NeuroImage. 2016;140:110–7.
34. Hejazi NS, Duncan WC Jr., Kheirkhah M, Kowalczyk A, Riedner B, Oppenheimer M, et al. Sleep Delta power, age, and sex effects in treatment-resistant depression. J Psychiatr Res. 2024;174:332–9.
35. Mennella R, Patron E, Palomba D. Frontal alpha asymmetry neurofeedback for the reduction of negative affect and anxiety. Behav Res Ther. 2017;92:32–40.
36. van der Vinne N, Vollebregt MA, van Putten M, Arns M. Stability of frontal alpha asymmetry in depressed patients during antidepressant treatment. Neuroimage Clin. 2019;24:102056.
37. Zehong C, Chin-Teng L, Weiping D, Mu-Hong C, Cheng-Ta L, Tung-Ping S. Identifying ketamine responses in Treatment-Resistant depression using a wearable forehead EEG. IEEE Trans Biomed Eng. 2019;66(6):1668–79.
38. Herweg NA, Solomon EA, Kahana MJ. Theta oscillations in human memory. Trends Cogn Sci. 2020;24(3):208–27.
39. Erratum K, et al. Hippocampal Theta oscillations support successful associative memory formation. J Neuroscience: Official J Soc Neurosci. 2021;41(6):1363.
40. Kaiser AK, Doppelmayr M, Iglseder B. EEG beta 2 power as surrogate marker for memory impairment: a pilot study. Int Psychogeriatr. 2017;29(9):1515–23.
41. Hall EE, Ekkekakis P, Petruzzello SJ. Regional brain activity and strenuous exercise: predicting affective responses using EEG asymmetry. Biol Psychol. 2007;75(2):194–200.
42. Shigeta TT, Leahy AA, Smith JJ, Eather N, Lubans DR, Hillman CH. Cardiorespiratory and muscular fitness associations with older adolescent cognitive control. J Sport Health Sci. 2021;10(1):82–90.
43. Hou M, Herold F, Zhang Z, Ando S, Cheval B, Ludyga S et al. Human dopaminergic system in the exercise-cognition link. Trends Mol Med. 2024.
44. Farren GL, Zhang T, Gu X, Thomas KT. Sedentary behavior and physical activity predicting depressive symptoms in adolescents beyond attributes of health-related physical fitness. J Sport Health Sci. 2018;7(4):489–96.
45. Li Z, Chen J, Feng Y, Zhong S, Tian S, Dai Z, et al. Differences in verbal and Spatial working memory in patients with bipolar II and unipolar depression: an MSI study. BMC Psychiatry. 2021;21:1–11.
46. Hou Y, Liu W, He T, Chen A. Association between the performance of executive function and the remission of depressive state after clinical treatment in patients with depression. J Affect Disord. 2024.
47. Nikolin S, Tan YY, Martin D, Moffa A, Loo CK, Boonstra TW. Behavioural and neurophysiological differences in working memory function of depressed patients and healthy controls. J Affect Disord. 2021;295:559–68.
48. Zhao Q, Wang X, Li SF, Wang P, Wang X, Xin X, et al. Relationship between physical activity and specific working memory indicators of depressive symptoms in university students. World J Psychiatry. 2024;14(1):148–58.
49. Schwefel M, Kaufmann C, Gutmann G, Henze R, Fydrich T, Rapp M, et al. Effect of physical exercise training on neural activity during working memory in major depressive disorder. J Affect Disord. 2025;372:269–78.
50. Schwefel MK, Kaufmann C, Gutmann G, Henze R, Fydrich T, Rapp M, et al. Physical fitness is associated with neural activity during working memory performance in major depressive disorder. NeuroImage: Clin. 2023;38:103401.
51. Ferguson CJ. An effect size primer: a guide for clinicians and researchers. 2016.
52. Jiang S. Factor structure of the Chinese version of the Beck depression inventory, version 2, among college students in China. Chin J Clin Psychol. 2020;28:299–305.
53. Beck AT, Steer RA, Carbin MG. Psychometric properties of the Beck depression inventory: Twenty-five years of evaluation. Clin Psychol Rev. 1988;8(1):77–100.
54. Q LIANG D. Stress levels and their relationship with physical activity among college students. Chin Mental Health J. 1994;01:5–6.
55. YAN J, TAO BL,SHI L LOUH, LI HY, LIU M. The relationship between extracurricular physical exercise and school adaptation of adolescents:a chain mediating model and gender difference. China Sport Sci Technol. 2020;56(10):11–8.
56. Hayes AF. Introduction to mediation, moderation, and conditional process analysis: A regression-based approach. Guilford; 2017.
57. LI T T, WU X Y, TAO S M, et al. Study on the relationship between physical activity and physical,mental health of college students. Chin J School Health. 2020;41(06):867–70.
58. Kirklewski SJ, Watson RJ, Lauckner C. The moderating effect of physical activity on the relationship between bullying and mental health among sexual and gender minority youth. J Sport Health Sci. 2023;12(1):106–15.
59. Mahnaz P, Alireza R, Gholamreza K, Hossein BM. Effect of Well-being therapy on depression, Self-Management, and blood glucose level in females with type II diabetes. J Diabetes Nurs. 2019;7(4):2345–5020.
60. Saffariantoosi K, Khaleghi MR. The mediating role of organizational citizenship behavior in the relationship between career self-efficacy and career success among construction project managers in Mashhad. Curr Psychol. 2024;43(28):23971–84.
61. Zhidong C, Wang X, Yin J, Song D, Chen Z. Effects of physical exercise on working memory in older adults: a systematic and meta-analytic review. Eur Rev Aging Phys Activity. 2021;18:1–15.
62. Kandola A, Ashdown-Franks G, Hendrikse J, Sabiston CM, Stubbs B. Physical activity and depression: towards Understanding the antidepressant mechanisms of physical activity. Neurosci Biobehav Rev. 2019;107:525–39.
63. De Miguel Z, Khoury N, Betley MJ, Lehallier B, Willoughby D, Olsson N, et al. Exercise plasma boosts memory and dampens brain inflammation via clusterin. Nature. 2021;600(7889):494–9.
64. Ren FF, Alderman BL, Wang WG, Chen FT, Zhou WS, Zong WJ et al. Effects of exercise training on executive functioning in adults with depression: A systematic review and Meta-Analysis of randomized controlled trials. Sports medicine (Auckland, NZ). 2023;53(9):1765–88.
65. Ren FF, Hillman CH, Wang WG, Li RH, Zhou WS, Liang WM, et al. Effects of aerobic exercise on cognitive function in adults with major depressive disorder: A systematic review and meta-analysis. Int J Clin Health Psychology: IJCHP. 2024;24(2):100447.
66. da Cunha LL, Feter N, Alt R, Rombaldi AJ. Effects of exercise training on inflammatory, neurotrophic and immunological markers and neurotransmitters in people with depression: A systematic review and meta-analysis. J Affect Disord. 2023;326:73–82.
67. Knyazev GG. EEG delta oscillations as a correlate of basic homeostatic and motivational processes. Neurosci Biobehav Rev. 2012;36(1):677–95.
68. Nielsen B, Hyldig T, Bidstrup F, Gonzalez-Alonso J, Christoffersen G. Brain activity and fatigue during prolonged exercise in the heat. Pflügers Archiv. 2001;442:41–8.
69. Edwards AM, Deakin G, Guy J. Brain and cardiorespiratory responses to exercise in hot and thermoneutral conditions. Int J Sports Med. 2016;37(10):779–84.
70. Balderston NL, Flook E, Hsiung A, Liu J, Thongarong A, Stahl S, et al. Patients with anxiety disorders rely on bilateral DlPFC activation during verbal working memory. Soc Cognit Affect Neurosci. 2020;15(12):1288–98.
71. Honey GD, Bullmore ET, Sharma T. Prolonged reaction time to a verbal working memory task predicts increased power of posterior parietal cortical activation. NeuroImage. 2000;12(5):495–503.

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