BMC Public Health

RESEARCH Open Access

Associations of physical activity and sedentary behavior with mental health among university students: the mediating role of cardiorespiratory fitness and moderating role of gender

Liya Xu[1], Yutian Ji[1] and Xu Wen[1*]

Abstract

Objective This study aimed to examine the associations between physical activity (PA), sedentary behavior, and mental health among university students, with a focus on the mediating role of cardiorespiratory fitness (CRF) and the potential moderating effect of gender.

Methods A cross-sectional survey was conducted among 233 university students from Zhejiang University. PA and sedentary behavior were assessed using the Global Physical Activity Questionnaire, mental health was measured by the Depression Anxiety Stress Scale (DASS-42), and CRF was evaluated via a treadmill-based VO_2max test. Harman's single-factor test was used to assess common method bias. Partial correlation, mediation, and moderation analyses were performed using SPSS 27.0 and the PROCESS 3.5 macro.

Results PA was positively associated with CRF ($\beta = 0.0016$, $P < 0.001$) and negatively associated with depression ($\beta = -0.0010$, $P < 0.001$), anxiety ($\beta = -0.0004$, $P = 0.004$), and stress ($\beta = -0.0014$, $P < 0.001$). Sedentary behavior was negatively associated with CRF ($\beta = -0.0096$, $P = 0.002$) but not significantly associated with mental health outcomes directly ($P > 0.05$). CRF was negatively associated with depression ($\beta = -0.0721$, $P = 0.040$), anxiety ($\beta = -0.0806$, $P = 0.040$), and stress ($\beta = -0.2502$, $P = 0.007$), and partially mediated the associations of PA and sedentary behavior with mental health. Gender significantly influenced depression ($F = 1.191$, $P = 0.276$) and anxiety ($F = 3.552$, $P = 0.061$), but did not significantly moderate the associations among PA, sedentary behavior, and CRF (interaction P-values > 0.05).

Conclusion CRF partially mediates the association between PA and mental health, suggesting that improved CRF may be one pathway through which PA supports psychological well-being. While sedentary behavior did not directly predict mental health outcomes, its negative impact on CRF may indirectly contribute to psychological distress.

*Correspondence:
Xu Wen
wenxu@zju.edu.cn

Full list of author information is available at the end of the article

Gender differences in mental health were observed, but gender did not significantly alter the relationships between the key study variables.

Keywords Physical activity, Sedentary behavior, Cardiorespiratory fitness, Mental health

Introduction

Mental health issues among university students have become an increasingly prominent concern worldwide. Mental health, as defined by the World Health Organization (WHO), is a state in which individuals can cope with the stresses of life, realize their potential, and contribute meaningfully to society [1]. However, university students often encounter stressors such as academic performance, career uncertainties, and social isolation, which can lead to a higher vulnerability to mental health disorders, including anxiety, depression, and sleep disturbances [2, 3]. A systematic review involving twenty-four studies reporting on the depression prevalence rate among university students had found that the average depression prevalence is 30.6% [4]. These concerns have been exacerbated in recent years by lifestyle changes and external factors such as the COVID-19 pandemic, leading to increased emotional distress and reduced psychological resilience among students [5, 6].

Physical activity (PA), defined as any skeletal muscle movement that results in energy expenditure, is widely recognized as a protective factor for mental well-being [7]. A systematic review by Singh et al. showed that regular PA is associated with better mental health outcomes, such as reduced symptoms of depression (MES = −0.43) and anxiety (MES = −0.42) [8]. Engaging in PA stimulates the release of endorphins and the modulation of the hypothalamic-pituitary-adrenal (HPA) axis, both of which are known to improve psychological resilience and reduce stress levels [9]. Regular PA has also been linked to improved self-esteem, social connectedness, and overall quality of life, factors that are particularly important for students in their academic and personal development [10, 11].

Sedentary behavior is not synonymous with physical inactivity, but a distinct behavior defined by activities undertaken at a low energy expenditure (≤ 1.5 metabolic equivalents of task [METs]) while sitting, lying or reclining [12]. Sedentary behavior, particularly excessive screen time, has been shown to have negative effects on mental health, contributing to symptoms of anxiety and depression [13, 14]. In a meta-analysis, the risk of depression from overall sedentary behavior was 31% higher over 13 cross-sectional studies, and 14% higher over 11 prospective studies [15]. The mechanisms through which PA and sedentary behavior influence mental health are multifaceted. As shown in Fig. 1, these behaviors may affect psychological outcomes via four key pathways: neurotransmitter regulation, emotional regulation, self-awareness, and social interaction. These mechanisms highlight how PA may enhance neurochemical, emotional, and social functioning, while sedentary behavior may impair them, contributing to divergent mental health outcomes. Thus, promoting PA among university students is crucial not only for physical health but also for improving mental health outcomes. These hypothesized pathways are further supported by the biopsychosocial model [16], which emphasizes that behavioral, physiological, and psychological systems interact to shape mental health. Within this framework, PA and sedentary behavior represent behavioral inputs, while CRF functions as a physiological mediator that may influence psychological outcomes. In addition, the neurobiological model of exercise and mental health suggests that improvements in CRF can enhance mental well-being through mechanisms such as hypothalamic-pituitary-adrenal (HPA) axis modulation, increased neurogenesis, and more effective emotion regulation [17]. These theoretical models provide a solid conceptual foundation for the mediation and moderation pathways examined in the present study.

Cardiorespiratory fitness (CRF), typically assessed by maximal oxygen uptake (VO2max), represents the integrated ability of the circulatory and respiratory systems to supply oxygen during sustained PA [18–21]. Hills et al. demonstrated that higher levels of CRF are associated with better mental health, as individuals with better cardiovascular health are more resilient to negative emotional experiences and are better able to manage stress [22]. Additionally, those who engage in extended periods of sedentary behavior, particularly when combined with low levels of PA, have an increased risk of low CRF [23, 24]. Given its physiological link to both PA and psychological health, CRF may serve as a potential pathway through which PA and sedentary behavior relate to mental health. In addition, gender differences in both CRF and mental health outcomes have been documented [25]. For example, females often report higher levels of psychological distress, while males tend to demonstrate higher CRF levels [26, 27].

However, despite these well-established associations, relatively few studies have examined the indirect role of CRF or tested whether gender moderates these relationships. To address these gaps, the present study incorporates a laboratory-based CRF assessment (VO_2max) and adopts a mediation analysis framework with all effects explicitly interpreted as correlational rather than causal, thereby enhancing both measurement rigor and analytical transparency. This study proposes the following

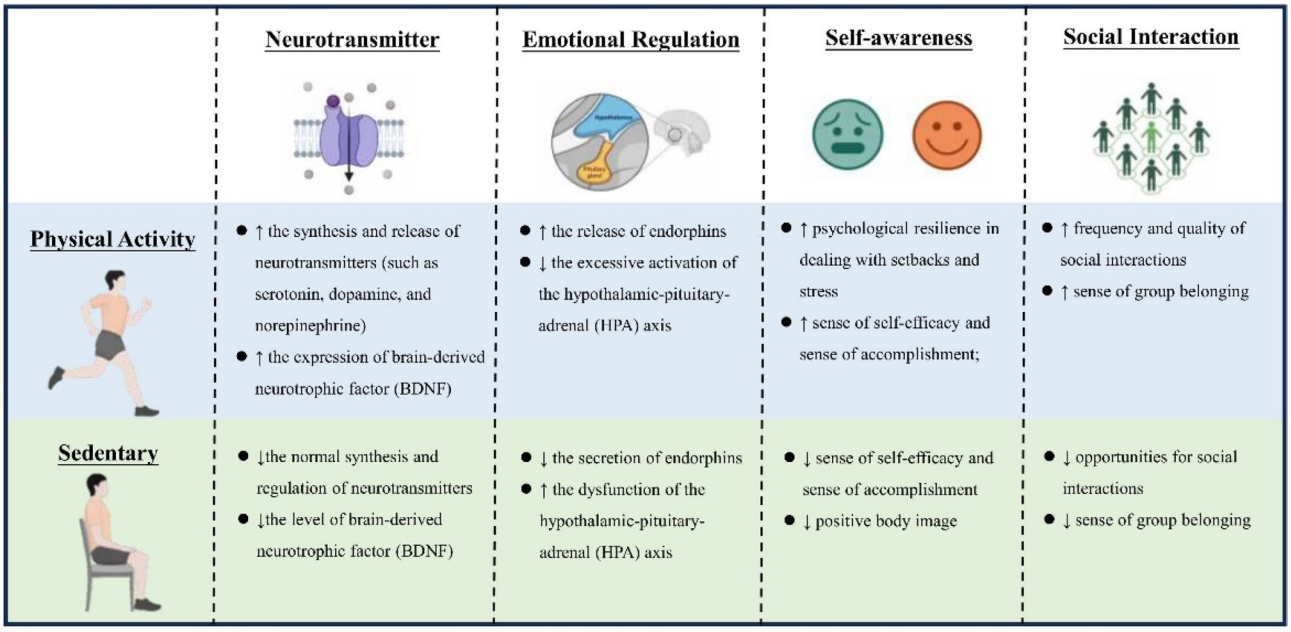

Fig. 1 Proposed biopsychosocial mechanisms linking physical activity and sedentary behavior to mental health outcomes This conceptual diagram summarizes four key pathways—neurotransmitter regulation, emotional regulation, self-awareness, and social interaction—through which behavioral patterns may influence psychological well-being

hypotheses: (1) CRF partially mediates the relationship between PA and symptoms of depression, anxiety, and stress; (2) CRF mediates the relationship between sedentary behavior and mental health; and (3) gender moderates these mediation effects. Given the cross-sectional design, the study aims to provide preliminary, correlational insights into these relationships rather than make causal claims. Future longitudinal or experimental studies are warranted to validate the observed associations and further explore the mechanisms involved.

Methods

Participants

Participants in this study were 233 university students (26.7% female) from Zhejiang University, with an average age of 24.24 ± 4.52 years. The participants were enrolled in various academic programs across different departments within the university.

Inclusion criteria: (1) full-time enrollment at Zhejiang University; (2) age between 18 and 30 years; (3) ability to safely complete a cardiopulmonary exercise test; and (4) provision of informed consent.

Exclusion criteria: (1) self-reported cardiovascular, pulmonary, neurological, or psychiatric disorders; (2) current use of medications that could affect cardiovascular or psychological function; and (3) recent musculoskeletal injuries limiting physical activity.

Students were informed about the voluntary and anonymous nature of participation, and they were assured they could withdraw from the study at any time. Written informed consent from participants was obtained before participation. The survey was distributed through an online platform, and all participants completed the electronic questionnaire during regular university hours. A total of 304 students were invited to participate, and 233 valid responses were retained for analysis after excluding incomplete submissions, resulting in an effective response rate of 76.6%. The study was approved by the Medical Ethics Committee of the Department of Psychology and Behavioral Science, Zhejiang University.

Measures

Participants self-reported birthdate, sex, and country of birth. Research assistants measured weight (recorded to the nearest 0.1 kg) and height (recorded to the nearest 0.1 cm), and body mass index (BMI) was calculated (weight (kg)/height $(m)^2$).

PA

The Global Physical Activity Questionnaire (GPAQ) is a self-administered, seven-day recall questionnaire designed to assess physical activity levels [28]. It has been widely used in various populations, including in China, with demonstrated reliability and validity. The questionnaire consists of questions regarding physical activity in three domains: work, transportation, and recreational activities. The intensity of these physical activities was measured in Metabolic Equivalents of Task (METs). One MET is defined as the energy expenditure at rest in a seated position, equivalent to a

consumption of 3.5 ml of oxygen per kg of body weight per minute. For the purpose of this analysis, the following MET intensities were applied: walking and bicycling = 4 METs, MPA = 4.0 METs, and VPA = 8.0 METs. The total weekly PA energy expenditure (expressed in MET-minutes/week, or MET*min/wk) is calculated as the sum of energy expended in walking, bicycling, MPA, and VPA. In addition, sedentary behavior was measured using a specific item from the GPAQ, which asked participants to report the average amount of time (in minutes) they spent sitting or reclining on a typical day, excluding time spent sleeping. This includes time spent sitting at a desk, watching television, using a computer or other screen devices, and during transportation.

Mental health

Mental problems were evaluated through the utilization of the Depression Anxiety and Stress Scale-42 (DASS-42) [29]. This scale, consisting of 42 items, encompasses three distinct dimensions: depression, anxiety, and stress. Participants were instructed to rate each item within a range from 0 (not applicable to oneself in any sense) to 3 (highly applicable or applicable for the majority of the time), based on their emotional experiences during the past week. Regarding these three dimensions, each dimension consists of a sub-score formed by the cumulative scores of 14 items, with a range from 0 to 42. In general, elevated scores within each sub - score as well as in the overall assessment signify more severe levels of depression, anxiety, and stress respectively.

CRF

CRF was assessed using a laboratory-based treadmill VO_{2max} test with a progressive incremental protocol. The test was conducted following standard maximal exercise testing guidelines and used the leveling-off criterion as the primary indicator of VO_{2max}, defined as a plateau in oxygen uptake despite increasing workload, along with a respiratory exchange ratio (RER) > 1.15. After a 5-minute warm-up at a self-selected light pace, participants rested for 5 min before beginning the test. To optimize the test duration, participants with lower physical condition started at 5 km/h, while well-trained participants began at 7 km/h, both at a 0% incline. The treadmill speed was then increased by 1 km/h every 3 min without changing the incline, continuing until participants reached volitional exhaustion. Heart rate (HR) was monitored using a chest strap, and VO_2 was continuously measured using a breath-by-breath analysis system (Cosmed K5 analyzer). The test was terminated when participants reached volitional fatigue, and VO_{2max} was recorded as the highest 30-second average oxygen uptake observed during the test. The results are expressed in milliliters of oxygen per kilogram of body weight per minute (ml/kg/min), with higher values indicating better cardiovascular and pulmonary health.

Statistical analysis

Statistical analyses were conducted using SPSS version 27.0 (IBM Corp., Armonk, NY, USA). Descriptive statistics were computed for all demographic and study variables, with continuous variables expressed as means and standard deviations and categorical variables presented as frequencies and percentages. Given the reliance on self-reported measures, the potential for common method bias was considered. Harman's single-factor test was employed to assess the extent of this bias, with the first unrotated factor accounting for less than 40% of the total variance, indicating no severe common method issue.

To examine differences in mental health outcomes and behavioral variables across demographic subgroups, one-way analysis of variance (ANOVA) was applied. Partial correlation analyses, controlling for gender, were performed to assess the bivariate associations among PA, sedentary behavior, CRF, and mental health indicators. To explore potential indirect associations, mediation and interaction analyses were performed using the PROCESS macro (version 3.5; Hayes, 2017) with 5,000 bootstrap samples. Model 4 was used to assess whether CRF (measured by VO_2max) statistically mediated the association between PA and mental health outcomes. To test the moderating role of gender on the relationship between PA or sedentary behavior and CRF, Model 7 was employed. Given the cross-sectional nature of the study and the known limitations of the Sobel test, we reported only bootstrap-based confidence intervals, in line with current best practices.

In addition to regression-based mediation and moderation analyses conducted using the PROCESS macro, structural equation modeling (SEM) was performed in AMOS 24.0 (IBM Corp.) to estimate and visualize the hypothesized mediation and moderated mediation pathways. The maximum likelihood estimation method was used to calculate standardized path coefficients, and model fit was evaluated using standard indices, including the chi-square statistic (χ^2), the Comparative Fit Index (CFI), the Tucker–Lewis Index (TLI), the Root Mean Square Error of Approximation (RMSEA), and the Standardized Root Mean Square Residual (SRMR). Given the cross-sectional nature of the data, all path relationships modeled using SEM are interpreted as correlational, and no causal inferences are drawn. The SEM results were consistent with the PROCESS-based findings, and the SEM model was included to provide a comprehensive visualization and confirmatory analysis of the proposed theoretical structure.

Table 1 Participants characteristics. Baseline characteristics of the study sample by gender (Mean ± SD)

Variables	Male (*n* = 171)	Female (*n* = 62)	F	*P*
Age (years)	24.03 ± 4.67	24.84 ± 4.07		
BMI (kg/m^2)	22.07 ± 2.52	20.80 ± 2.16		
Depression (scores)	8.51 ± 6.10	9.50 ± 6.19	1.191	0.276
Anxiety (scores)	5.49 ± 4.84	6.85 ± 5.00	3.552	0.061
Stress (scores)	14.11 ± 11.58	16.68 ± 11.70	2.221	0.137
PA (MET*min/wk)	3002.67 ± 2307.14	1875.55 ± 1157.10	13.535***	< 0.001
Sedentary (min/d)	432.75 ± 186.75	496.13 ± 173.45	5.439*	0.021
VO_{2max} (ml/min/kg)	52.12 ± 7.46	42.61 ± 7.81	72.117***	< 0.001

F and *P* values represent results of one-way ANOVA between male and female participants.*: $P < 0.05$; **: $P < 0.01$; ***: $P < 0.001$

Results

Common method bias test

Harman's single-factor test was conducted to assess the potential presence of common method bias. Results from the unrotated exploratory factor analysis indicated that multiple factors had eigenvalues greater than 1, with the first factor accounting for 30.2% of the total variance—well below the critical threshold of 40% [30]. These findings suggest that common method bias was not a significant concern in the current study.

Participants characteristics

Participant demographics are summarized in Table 1. A total of 233 university students were included in the analysis, comprising 171 males (73.4%) and 62 females (26.7%). The mean age was 24.03 ± 4.67 years for males and 24.84 ± 4.07 years for females. The average body mass index (BMI) was 22.07 ± 2.52 kg/m² for males and 20.80 ± 2.16 kg/m² for females. All participants had BMI values within the normal range (18.5–24.9 kg/m²), and due to the absence of underweight, overweight, or obese individuals, BMI was not included as a covariate in the statistical models, as its minimal variation was unlikely to introduce confounding effects.

In addition, one-way ANOVA revealed significant gender differences in several behavioral and physiological variables. Specifically, males reported significantly higher levels of PA ($F = 13.535$, $P < 0.001$) and VO_{2max} ($F = 72.117$, $P < 0.001$), while females reported more sedentary time than males ($F = 5.439$, $P = 0.021$). In contrast, no significant main effects of gender were observed for mental health outcomes. Depression ($F = 1.191$, $P = 0.276$), anxiety ($F = 3.552$, $P = 0.061$), and stress scores ($F = 2.221$, $P = 0.137$) did not significantly differ between genders. Given these findings, gender was not included as a direct predictor in the SEM models, but was tested for moderation effects in subsequent analyses.

Partial correlation analysis of PA, sedentary behavior, CRF, and mental health

Given the significant gender differences observed in depression and anxiety, gender was statistically controlled in the subsequent partial correlation analysis (Table 2). PA was positively correlated with VO_{2max} ($R = 0.316$, $P < 0.001$) and negatively correlated with depression ($R = -0.343$, $P < 0.001$), anxiety ($R = -0.167$, $P = 0.011$), and stress ($R = -0.236$, $P < 0.001$).

Sedentary time was negatively correlated with VO_{2max} ($R = -0.153$, $P = 0.02$), while VO_{2max} was negatively correlated with depression ($R = -0.213$, $P = 0.001$), anxiety ($R = -0.155$, $P = 0.018$), and stress ($R = -0.238$, $P < 0.001$). Additionally, depression was strongly and positively correlated with both anxiety ($R = 0.796$, $P < 0.001$) and stress ($R = 0.750$, $P < 0.001$), while anxiety was highly positively correlated with stress ($R = 0.876$, $P < 0.001$).

Indirect association of CRF in the relationship between PA and mental health

To examine the potential indirect association between PA and mental health outcomes via CRF, Model 4 of the PROCESS macro was applied (Table 3). Mental health outcomes—including depression, anxiety, and stress—were treated as dependent variables, with PA as the independent variable.

Results indicated that higher levels of PA were significantly associated with lower levels of depression ($\beta = -0.0010$, $95\%CI = -0.0014$ - -0.0007, $P < 0.001$), anxiety ($\beta = -0.0004$, $95\%CI = -0.0007$ - -0.0001, $P = 0.004$),

Table 2 Partial correlation analysis of PA, sedentary behavior, CRF, and DASS scores

Variables	PA	Sedentary	VO_{2max}	Depression	Anxiety	Stress
PA	1					
Sedentary	−0.109	1				
VO_{2max}	0.316***	−0.153*	1			
Depression	−0.343***	−0.046	−0.213**	1		
Anxiety	−0.167*	−0.062	−0.155*	0.796***	1	
Stress	−0.236***	−0.090	−0.238***	0.750***	0.876***	1

Gender was statistically controlled in the partial correlation analysis.*: $P < 0.05$; **: $P < 0.01$; ***: $P < 0.001$

Table 3 Mediating effect analyses

Dependent variables	Independent variables	β	SE	t	LLCL	ULCL	R^2	F
Mental health	PA							
Depression		−0.0010***	0.0002	−5.6744	−0.0014	−0.0007	0.1223	32.198***
Anxiety		−0.0004**	0.0001	−2.9488	−0.0007	−0.0001	0.0363	8.696**
Stress		−0.0014***	0.0003	−3.9426	−0.0021	−0.0007	0.0630	15.544***
CRF	PA	0.0016***	0.0002	6.3024	0.0011	0.0020	0.1467	39.720***
Mental health								
Depression	PA	−0.0009***	0.0002	−4.6720	−0.0013	−0.0005	0.1311	17.357***
	CRF	−0.0721*	0.0472	−1.5264	−0.1651	−0.0210		
Anxiety	PA	−0.0003*	0.0002	−1.9607	−0.0006	0.0000	0.0534	6.491**
	CRF	−0.0806*	0.0395	−2.0412	−0.1583	0.0028		
Stress	PA	−0.0010**	0.0004	−2.6472	−0.0017	−0.0003	0.0924	11.712***
	CRF	−0.2502**	0.0917	−2.7286	−0.4309	−0.0695		
CRF	PA	−0.0012	0.0007	−1.6490	−0.0027	0.0002	0.1228	10.6845***
	Gender	−0.5415	1.5825	−0.3422	−3.6595	2.5765		
	Interaction effect [a]	0.0002	0.0007	0.2931	−0.0011	0.0015		
Mental health	Sedentary behavior							
Depression		−0.0012	0.0022	−0.5282	−0.0054	0.0031	0.0012	0.2790
Anxiety		−0.0011	0.0017	−0.6413	−0.0046	0.0023	0.0018	0.4113
Stress		−0.0046	0.0041	−1.1216	−0.0128	0.0035	0.0054	1.2579
CRF	Sedentary	−0.0096**	0.0030	−3.2023	−0.0155	−0.0037	0.0425	10.2544**
Mental health								
Depression	Sedentary	−0.0028	0.0022	−1.2793	−0.0070	0.0015	0.0554	6.7449**
	CRF	−0.1688***	0.0465	−3.6326	−0.2604	−0.0773		
Anxiety	Sedentary	−0.0023	0.0017	−1.3024	−0.0057	0.0012	0.0447	5.3748**
	CRF	−0.1202**	0.0374	−3.2127	−0.1940	−0.0465		
Stress	Sedentary	0.0083*	0.0041	−2.0385	−0.0163	−0.0003	0.0814	10.1868***
	CRF	−0.3798***	0.0871	−4.3609	−0.5514	−0.2082		
CRF	Sedentary	0.0078	0.0128	0.6121	−0.0174	0.0330	0.0229	1.7852
	Gender	8.1908	5.0200	1.6316	−1.7004	18.0820		
	Interaction effect [b]	−0.0109	0.0098	−1.1177	−0.0302	0.0083		

a, *PA* × Gender; b, Sedentary × Gender; *SE* standard error; *LLCL* lower limit of the 95% confidence interval; *ULCL* upper limit of the 95% confidence interval. *: $P<0.05$; **: $P<0.01$; ***: $P<0.001$

and stress (β = −0.0014, *95%CI* = − 0.0021 - −0.0007, $P<0.001$). When CRF was included as a mediator, PA remained a significant positive predictor of CRF ($\beta = 0.0016$, *95%CI* = 0.0011–0.0020, $P<0.001$). In models including both PA and CRF, PA continued to show significant inverse associations with depression (β = −0.0009, *95%CI* = − 0.0013 - −0.0005, $P<0.001$), anxiety (β = −0.0003, *95%CI* = − 0.0006–0.0000, $P=0.04$), and stress (β = −0.0010, *95%CI* = − 0.0017 - −0.0003, $P=0.009$). Furthermore, CRF was inversely associated with depression (β = −0.0721, *95%CI* = − 0.1651 - −0.0210, $P=0.04$), anxiety (β = −0.0806, *95%CI* = − 0.1583 – 0.0028, $P=0.04$), and stress (β = −0.2502, *95%CI* = − 0.4309 - −0.0695, $P=0.007$).

These findings suggest that CRF serves as a partial statistical mediator in the relationship between PA and mental health outcomes. To explore whether this indirect association was moderated by gender, Model 7 of the PROCESS macro was employed. The interaction term between PA and gender did not significantly predict CRF ($\beta = 0.0002$, *95%CI* = − 0.0011–0.0015, $P=0.77$), indicating no moderating effect.

In addition to the regression-based analyses, a structural equation model (SEM) was estimated using AMOS to visualize and test the proposed mediation pathway from PA to mental health via CRF (Fig. 2). The standardized path coefficients indicated that PA was positively associated with CRF ($\beta = 0.463$), while the interaction term PA × Gender also showed a positive association with CRF ($\beta = 0.287$), although the effect was not statistically significant. CRF was inversely associated with the latent mental health construct (β = −0.170), and PA also had a direct negative effect on mental health (β = −0.186).

The latent variable of mental health was indicated by three observed variables: depression (loading = 0.693), anxiety (loading = 0.719), and stress (loading = 0.604). However, the model exhibited poor overall fit to the data: $\chi^2(8) = 79.880$, $P<0.001$; $\chi^2/df = 9.985$; CFI = 0.901; TLI = 0.814; RMSEA = 0.197 (*90%CI*: 0.159–0.237); SRMR = 0.303. While the CFI approached the acceptable

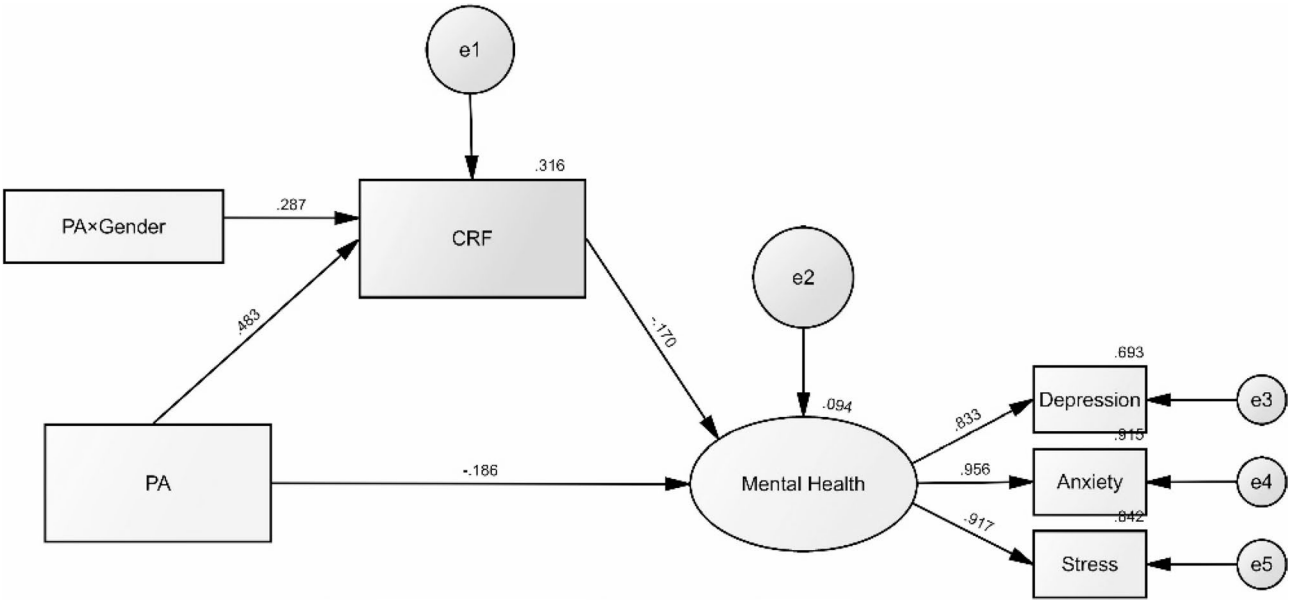

Fig. 2 Structural equation model examining the mediating effect of cardiorespiratory fitness (CRF) in the association between physical activity (PA) and mental health outcomes, with gender as a moderator The model includes a latent mental health construct indicated by depression, anxiety, and stress. Standardized path coefficients are shown. The interaction term (PA× Gender) was included to test moderation. All effects are interpreted as correlational due to the cross-sectional design. The model was estimated using AMOS with maximum likelihood estimation

threshold, both TLI, RMSEA, and SRMR values indicated suboptimal model fit. Therefore, the PROCESS-based mediation model remains the primary basis for interpretation in this study, with the SEM results included for conceptual illustration.

Indirect association of CRF in the relationship between sedentary behavior and mental health

As sedentary behavior is conceptually and behaviorally independent from PA, a separate mediation analysis was conducted to explore the role of CRF in the association between sedentary behavior and mental health outcomes (Table 3).

Direct associations between sedentary behavior and depression (β = −0.0012, *95%CI* = − 0.0054 − 0.0031, P = 0.60), anxiety (β = −0.0011, *95%CI* = − 0.0046 − 0.0023, P = 0.52), and stress (β = −0.0046, *95%CI* = − 0.0128 − 0.0035, P = 0.26) were not statistically significant. Nevertheless, after including CRF as a mediator, sedentary behavior was found to significantly predict lower CRF levels (β = −0.0096, *95%CI* = − 0.0155 - −0.0037, P = 0.002). Notably, in the model for stress, sedentary behavior showed a small but significant positive association (β = 0.0083, *95%CI* = − 0.0163 - −0.0003, P = 0.04).

CRF remained a significant negative predictor of depression (β = −0.1688, *95%CI* = − 0.2604 - −0.0773, P < 0.001), anxiety (β = −0.1202, *95%CI* = − 0.1940 - −0.0465, P = 0.002), and stress (β = −0.3798, *95%CI* = − 0.5514 - −0.2082, P < 0.001), suggesting that CRF partially mediated the relationship between sedentary behavior and mental health outcomes.

To test for gender moderation, Model 7 of the PROCESS macro was again used. The interaction between sedentary behavior and gender was not statistically significant (β = −0.0109, *95%CI* = − 0.0302 − 0.0083, P = 0.26), indicating that the indirect pathway was not moderated by gender.

In addition to the PROCESS-based moderation models, a structural equation model (SEM) was also constructed in AMOS to examine the moderated mediation pathway linking sedentary behavior to mental health via CRF, with gender as a moderator (Fig. 3). The standardized path coefficients indicated that sedentary behavior was negatively associated with CRF (β = −0.209), and CRF was inversely associated with mental health (β = −0.253). Sedentary behavior also showed a direct negative effect on mental health (β = −0.106). The interaction term (Sedentary × Gender) negatively predicted CRF (β = −0.065), suggesting a potential moderating effect. The latent construct of mental health was indicated by depression (loading = 0.686), anxiety (loading = 0.807), and stress (loading = 0.915). The overall model demonstrated mixed fit to the data: $\chi^2(8) = 10.731$, P = 0.217; $\chi^2/df = 1.341$; CFI = 0.995; TLI = 0.992; RMSEA = 0.038 (*90%CI*: 0.000–0.091), PCLOSE = 0.576, SRMR = 0.468. While CFI, TLI, and RMSEA indicated excellent fit, the SRMR was notably high, suggesting that the model may not adequately reproduce all observed covariances. Despite this, the model structure provides a useful

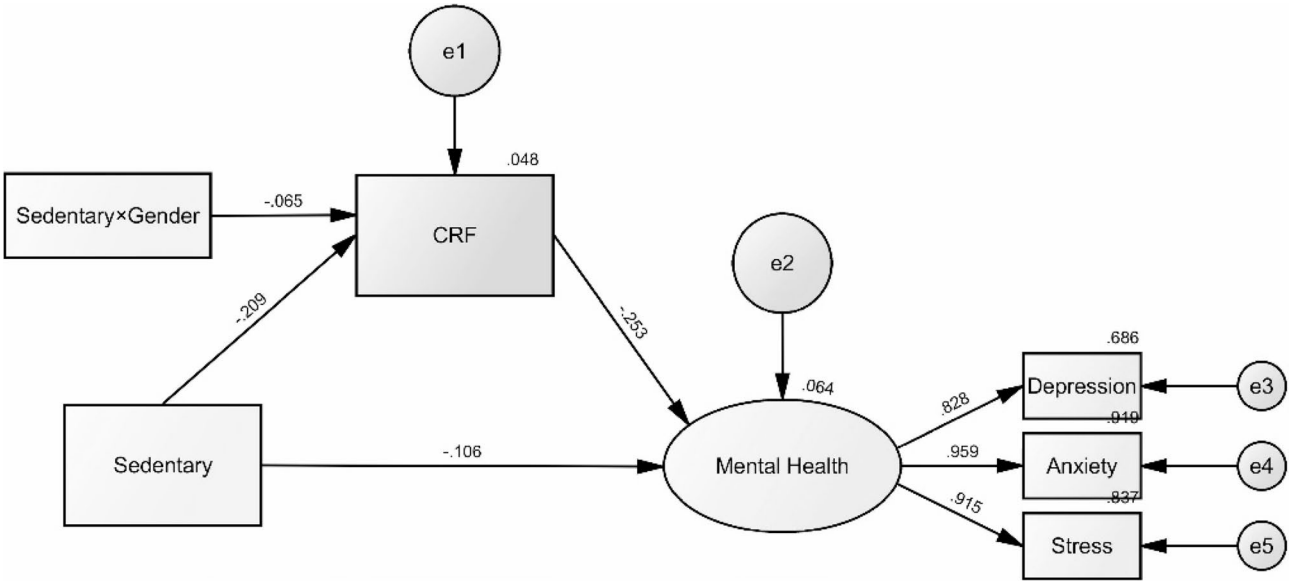

Fig. 3 Structural equation model examining the moderated mediation effect of cardiorespiratory fitness (CRF) in the association between sedentary behavior and mental health outcomes, with gender as a moderator The model includes a latent mental health construct indicated by depression, anxiety, and stress. Standardized path coefficients are shown. The interaction term (Sedentary × Gender) was included to test moderation. All effects are interpreted as correlational due to the cross-sectional design. The model was estimated using AMOS with maximum likelihood estimation

conceptual framework for exploring the relationships among sedentary behavior, CRF, and mental health.

Discussion

This study examined the associations between PA, sedentary behavior, CRF, and mental health among university students. The findings showed that higher levels of PA were associated with fewer mental health problems, with CRF partially mediating this relationship. Although sedentary behavior was not directly related to mental health outcomes, it was indirectly associated via CRF, suggesting that lower fitness levels may link sedentary lifestyles to psychological distress.

PA and mental health

Association between PA and mental health

This study found that higher levels of PA were significantly associated with lower levels of depression, anxiety, and stress among university students, aligning with previous findings that regular PA contributes to improved mental health [31]. Moreover, CRF was shown to partially mediate these associations, suggesting that PA may support mental well-being partly through its role in enhancing aerobic capacity. Notably, even after adjusting for gender, the associations remained significant, highlighting the robustness of this pathway.

Evidence from clinical and population-based studies supports the link between CRF and psychological outcomes. In a 12-week exercise trial, Rahman et al. found that the increase in CRF predicted a greater reduction in the symptoms of patients with depression, which was independent of exercise intensity, age and body weight, and they also found that the improvement of CRF increased the probability of a treatment response at follow-up (*OR* = 3.73, *95%CI*: 1.22–11.43) [32]. Additionally, another systematic review targeting patients with depression and those without found that there was a moderate correlation (*CC* = – 0.16, *95%CI*: –0.21—0.10) between CRF and the severity of depressive symptoms in 16 randomized controlled trials and population-based studies [33].

Physiological mechanisms linking PA, CRF, and mental health

It is well-established that individuals who regularly engage in moderate- to high-intensity aerobic exercises tend to exhibit better CRF (higher VO_{2max}) [34, 35]. Such physical activity promotes the release of key neurotransmitters in the brain, including serotonin and dopamine, and improves cerebral oxygenation and vascular function [36–38] (Figure 4).

While neurobiological processes were not directly measured in this study, prior research suggests that physical activity may influence mental health through the modulation of neurotransmitters such as serotonin and dopamine. These chemicals play important roles in emotional regulation, memory, and cognitive flexibility [39–42]. Regular aerobic exercise has also been associated with elevated levels of brain-derived neurotrophic factor (BDNF), which supports neuroplasticity and cognitive function [43, 44]. Beyond neurochemical effects, exercise may also exert antidepressant benefits by modulating systemic inflammation. Lavebratt et al. demonstrated that

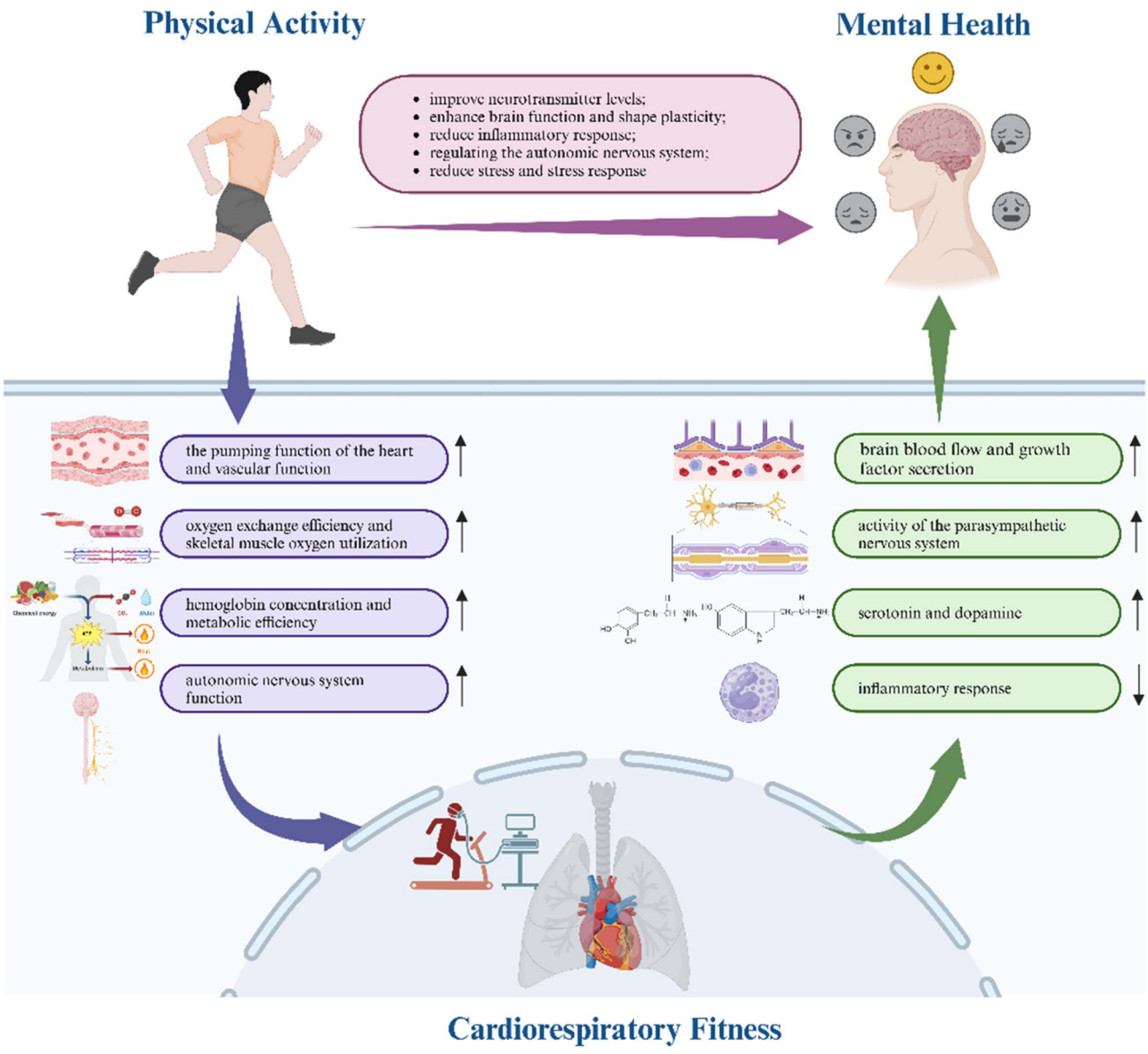

Fig. 4 The physiological mechanism by which physical activity regulates mental health through cardiopulmonary fitness Physical activity enhances cardiorespiratory fitness by improving heart and vascular pumping functions, oxygen exchange efficiency and skeletal muscle oxygen utilization, hemoglobin concentration, metabolic efficiency, and autonomic nervous system functions. Elevated cardiorespiratory fitness subsequently promotes mental health by increasing brain blood flow, secretion of growth factors, parasympathetic nervous system activity, serotonin and dopamine levels, and reducing inflammatory responses

patients with depressive symptoms who engaged in exercise interventions exhibited significantly reduced serum interleukin-6 (IL-6) levels, along with improved depression scores compared to control groups [45].

In addition, individuals with higher CRF exhibit more effective oxygen and nutrient transport to the brain, improved cerebral perfusion, and better endothelial function, including greater nitric oxide availability and vascular elasticity [46, 47]. These physiological adaptations help sustain a stable neural environment conducive to emotional well-being.

Despite these benefits, CRF levels have declined globally over recent decades, particularly among youth [48]. In the United States, it is estimated that only about 40% of youths aged 12 to 15 meet the criteria for healthy CRF levels [49]. Given this downward trend, designing targeted physical activity interventions with appropriate intensity, frequency, and duration is essential for improving CRF and promoting overall health. Evidence suggests that an aerobic exercise program performed three times per week, lasting 45 min per session over a three-week period, can increase CRF by 18% in younger individuals (average age: 23 years) [50].

Sedentary and mental health

Mixed evidence and underlying mechanisms

Although the present study found a significant negative association between sedentary behavior and CRF, the direct relationships between sedentary behavior and mental health outcomes—including depression, anxiety, and stress—were not statistically significant. This finding is consistent with some prior research, which reported no clear associations between sedentary time and psychological symptoms in either prospective or interaction models [51]. However, this result contradicts some research findings [52, 53].

One possible explanation for these discrepancies lies in the complexity of underlying mechanisms. Sedentary behavior has been linked to elevated levels of inflammatory markers such as C-reactive protein and interleukin-6, both of which are associated with increased risks of depression and anxiety [54, 55]. Moreover, screen-based sedentary activities—such as prolonged television viewing or computer use—may reduce opportunities for face-to-face interaction and social engagement, thereby contributing to emotional isolation and depressive symptoms [56, 57]. Variability in research designs, measurement methods, and population characteristics may also account for inconsistent findings. For instance, reliance on self-reported sedentary time introduces recall bias, while different mental health scales vary in sensitivity and focus. Future studies should aim to standardize and optimize assessment tools to improve measurement accuracy and cross-study comparability.

The mediating role of CRF and practical implications

Importantly, this study identified a significant indirect effect of sedentary behavior on mental health via CRF. Specifically, prolonged sedentary time was associated with reduced CRF, which in turn was linked to increased psychological distress. This finding highlights CRF as a partial statistical mediator and suggests that interventions aimed at preserving or enhancing CRF could mitigate the potential adverse effects of sedentary lifestyles on mental health. From a practical perspective, these results underscore the importance of targeting CRF as a buffer against the psychological risks of sedentary behavior. For individuals who cannot avoid prolonged sitting due to occupational or lifestyle factors, incorporating regular moderate-intensity exercise may help offset declines in CRF and reduce vulnerability to mental health issues. Additionally, future research should explore optimal thresholds and interruption patterns for sedentary behavior to preserve CRF and, by extension, psychological well-being. Questions such as whether frequent breaks or specific daily sedentary time limits are more protective remain to be answered.

Furthermore, the mediating role of CRF may vary across populations. For example, older adults or individuals with chronic conditions typically exhibit lower baseline CRF and reduced physiological adaptability, which may amplify the mental health consequences of sedentary behavior. Tailored interventions that account for individual health status, age, and functional capacity are therefore warranted. At the public health level, these findings reinforce the need to raise awareness of the long-term effects of sedentary behavior and promote simple, accessible physical activity strategies—such as light stretching, walking, or desk-based exercises—to help maintain CRF and support mental well-being.

Moderating effect of gender

Absence of gender moderation in the PA–CRF relationship

In this study, gender was found to significantly influence depression and anxiety levels, with females generally reporting higher psychological distress. However, gender did not demonstrate a significant moderating effect in the associations among PA, sedentary behavior, and CRF. This suggests that while mental health disparities exist between males and females, the strength of the relationship between PA and CRF does not substantially differ by gender.

From a physiological perspective, this may reflect fundamental similarities between men and women in cardiopulmonary structure and function, as well as in their adaptive responses to exercise [58]. Although there are known differences in hormonal profiles and body composition between genders, these factors do not appear to exert a dominant regulatory effect on how PA improves CRF. For example, whether it is men or women, regular aerobic exercises can enhance cardiac function and improve the efficiency of pulmonary ventilation, thereby increasing CRF [59, 60].

However, the reasons for the significant gender differences in mental health may be more related to sociocultural factors [61]. conducted a cross-sectional study on a sample of 133 women and 90 men, and the results of the study showed that women's physical health conditions were worse than those of men, while the gender differences in mental health conditions were relatively small [62]. This is mainly because women tend to face more stressors in society, such as the challenges of balancing family and career and the pressure of social expectations [63]. These factors may make them more prone to depression and anxiety.

Gender-Sensitive recommendations for intervention

Given the absence of a moderating effect but the presence of gender-specific mental health needs, future interventions should consider tailoring physical activity strategies accordingly. For female participants, integrating

psychological support into exercise programs—such as offering stress management workshops or access to emotional counseling—may address both physiological and emotional dimensions of health. Such holistic approaches may be more effective in alleviating symptoms of depression and anxiety in women.

For male participants, interventions may focus on enhancing motivation and adherence through structured, goal-oriented, or competitive physical activity programs. Emphasizing the broader health benefits of exercise, including stress resilience and long-term wellness, may also be effective in promoting PA participation and indirectly improving mental health outcomes.

Limitations

While this study offers valuable insights into the relationships among PA, sedentary behavior, CRF, and mental health, several limitations should be acknowledged. First, given the cross-sectional study design, the associations found should be interpreted with caution. Although the mediation models are statistically valid, they do not allow for establishing a temporal sequence or causality. Longitudinal or experimental studies are needed to validate these mechanisms. Second, the PA and sedentary behavior data were obtained through self-report questionnaires, which may be affected by recall bias or social desirability. These biases may influence the accuracy of the estimated associations. Future studies are encouraged to incorporate objective tools, such as accelerometers or wearable sensors, to obtain more reliable measurements. Third, the gender distribution in our sample was skewed, with a relatively low proportion of female participants (26.7%), which may limit the generalizability of the findings across genders. Moreover, since all participants were recruited from a single university, the external validity of the findings may be constrained. Future studies should aim to include more gender-balanced and geographically diverse samples to improve representativeness. Finally, although CRF was identified as a partial mediator, other potential mediating variables—such as social support, sleep quality, or psychological resilience—were not included in the current model. Future studies should consider a broader range of mediators to more comprehensively understand the pathways linking physical behavior patterns to mental health outcomes.

Conclusion

This study demonstrated that PA can improve college students' mental health problems by enhancing CRF, and CRF played a partial mediating role in this process. Although sedentary behavior did not have a significant direct relationship with mental health, it indirectly affected mental health by influencing CRF. Therefore, it is of great practical significance to promote college students' participation in PA, reduce sedentary time, and improve mental health by enhancing CRF. Future research should further explore how to design personalized intervention measures to improve college students' CRF and thus effectively improve their mental health.

Acknowledgements
Not applicable.

Authors' contributions
L.X.: Conceptualization, Data Curation, Visualization, Writing - Original Draft; Y.J.: Formal Analysis, Validation, Visualization; X.W.: Supervision, Writing - Review & Editing. All the authors made significant contributions to the final manuscript and approved its publication.

Funding
No sources of funding were used to assist in the preparation of this review.

Data availability
Due to ethical and privacy considerations, the data are not publicly available. However, de-identified data supporting the findings of this study may be made available from the corresponding author upon reasonable request, subject to institutional approval.

Declarations

Ethics approval and consent to participate
This study was conducted in accordance with the principles outlined in the Declaration of Helsinki (https://www.wma.net/policies-post/wma-declaration-of-helsinki/). The study protocol was reviewed and approved by the [Medical Ethics Committee of the Department of Psychology and Behavioral Science, Zhejiang University (approval number: [2023085])], and written informed consent was obtained from all participants prior to enrollment.

Consent for publication
Not Applicable.

Competing interests
The authors declare no competing interests.

Author details
[1]College of Education, Zhejiang University, Hangzhou, China

Received: 1 April 2025 / Accepted: 20 August 2025
Published online: 01 October 2025

References

1. Brundtland GH. From the world health organization. Mental health: new understanding, new hope. JAMA. 2001;286(19):2391.
2. Hunt J, Eisenberg D. Mental health problems and help-seeking behavior among college students. J Adolesc Health. 2010;46(1):3–10.
3. Sheldon E, Simmonds-Buckley M, Bone C, Mascarenhas T, Chan N, Wincott M, Gleeson H, Sow K, Hind D, Barkham M. Prevalence and risk factors for mental health problems in university undergraduate students: A systematic review with meta-analysis. J Affect Disord. 2021;287:282–92.
4. Ibrahim AK, Kelly SJ, Adams CE, Glazebrook C. A systematic review of studies of depression prevalence in university students. J Psychiatr Res. 2013;47(3):391–400.
5. Son C, Hegde S, Smith A, Wang X, Sasangohar F. Effects of COVID-19 on college students' mental health in the united states: interview survey study. J Med Internet Res. 2020;22(9):e21279.
6. Cao W, Fang Z, Hou G, Han M, Xu X, Dong J, Zheng J. The psychological impact of the COVID-19 epidemic on college students in China. Psychiatry Res. 2020;287: 112934.
7. Caspersen CJ, Powell KE, Christenson GM. Physical activity, exercise, and physical fitness: definitions and distinctions for health-related research. Public Health Rep. 1985;100(2):126–131.

8. Singh B, Olds T, Curtis R, Dumuid D, Virgara R, Watson A, Szeto K, O'Connor E, Ferguson T, Eglitis E, Miatke A, Simpson CE, Maher C. Effectiveness of physical activity interventions for improving depression, anxiety and distress: an overview of systematic reviews. Br J Sports Med. 2023;57(18):1203–9.
9. Arvidson E, Dahlman AS, Börjesson M, Gullstrand L, Jonsdottir IH. The effects of exercise training on hypothalamic-pituitary-adrenal axis reactivity and autonomic response to acute stress-a randomized controlled study. Trials. 2020;21(1):888.
10. Teuber M, Leyhr D, Sudeck G. Physical activity improves stress load, recovery, and academic performance-related parameters among university students: a longitudinal study on daily level. BMC Public Health. 2024;24(1):598.
11. Fong Yan A, Nicholson LL, Ward RE, Hiller CE, Dovey K, Parker HM, Low LF, Moyle G, Chan C. The effectiveness of dance interventions on psychological and cognitive health outcomes compared with other forms of physical activity: a systematic review with meta-analysis. Sports Med. 2024;54(5):1179–205.
12. Tremblay MS, Aubert S, Barnes JD, Saunders TJ, Carson V, Latimer-Cheung AE, et al. Sedentary behavior research net work (SBRN)—Terminology consensus project process and outcome. Int J Behav Nutr Phys Act. 2017;14(1):75.
13. Hoare E, Milton K, Foster C, Allender S. The associations between sedentary behaviour and mental health among adolescents: a systematic review. Int J Behav Nutr Phys Act. 2016;13(1):108.
14. de Rezende LF, Rodrigues Lopes M, Rey-López JP, Matsudo VK, Luiz Odo C. Sedentary behavior and health outcomes: an overview of systematic reviews. PLoS One. 2014;9(8):e105620.
15. Zhai L, Zhang Y, Zhang D. Sedentary behaviour and the risk of depression: a meta-analysis. Br J Sports Med. 2015;49(11):705–9.
16. Engel GL. The need for a new medical model: a challenge for biomedicine. Science. 1977;196(4286):129–36.
17. Lubans D, Richards J, Hillman C, Faulkner G, Beauchamp M, Nilsson M, Kelly P, Smith J, Raine L, Biddle S. Physical activity for cognitive and mental health in youth: a systematic review of mechanisms. Pediatrics. 2016;138(3):e20161642.
18. Hallal PC, Lee IM. Prescription of physical activity: an undervalued intervention. Lancet. 2013;381:356–7.
19. Neufer PD, Bamman MM, Muoio DM, Bouchard C, Cooper DM, Goodpaster BH, Booth FW, Kohrt WM, Gerszten RE, Mattson MP, Hepple RT, Kraus WE, Reid MB, Bodine SC, Jakicic JM, Fleg JL, Williams JP, Joseph L, Evans M, Maruvada P, Rodgers M, Roary M, Boyce AT, Drugan JK, Koenig JI, Ingraham RH, Krotoski D, Garcia-Cazarin M, McGowan JA, Laughlin MR. Understanding the cellular and molecular mechanisms of physical activity-induced health benefits. Cell Metab. 2015;22:4–11.
20. Franklin BA, Wedig IJ, Sallis RE, Lavie CJ, Elmer SJ. Physical activity and cardiorespiratory fitness as modulators of health outcomes: a compelling research based case presented to the medical community. Mayo Clin Proc. 2023;98:316–31.
21. Isath A, Koziol KJ, Martinez MW, Garber CE, Martinez MN, Emery MS, Baggish AL, Naidu SS, Lavie CJ, Arena R, Krittanawong C. Exercise and cardiovascular health: a state-of-the-art review. Prog Cardiovasc Dis. 2023;79:44–52.
22. Hills AP, Jayasinghe S, Arena R, Byrne NM. Global status of cardiorespiratory fitness and physical activity - Are we improving or getting worse? Prog cardiovasc dis. 2024 Mar-Apr;83: 16–22.
23. Lee DC, Sui X, Ortega FB, Kim YS, Church TS, Winett RA, Ekelund U, Katzmarzyk PT, Blair SN. Comparisons of leisure-time physical activity and cardiorespiratory fitness as predictors of all-cause mortality in men and women. Br J Sports Med. 2011;45:504–10.
24. Lavie CJ, Ozemek C, Carbone S, Katzmarzyk PT, Blair SN. Sedentary behavior, exercise, and cardiovascular health. Circ Res. 2019;124(5):799–815.
25. Ji H, Gulati M, Huang TY, Kwan AC, Ouyang D, Ebinger JE, Casaletto K, Moreau KL, Skali H, Cheng S. Sex differences in association of physical activity with all-cause and cardiovascular mortality. J Am Coll Cardiol. 2024;83(8):783–93.
26. Laurent CM, Vervaecke LS, Kutz MR, Green JM. Sex-specific responses to self-paced, high-intensity interval training with variable recovery periods. J Strength Cond Res. 2014;28(4):920–7.
27. Wheatley CM, Snyder EM, Johnson BD, Olson TP. Sex differences in cardiovascular function during submaximal exercise in humans. Springerplus. 2014;3:445.
28. Bull FC, Maslin TS, Armstrong T. Global physical activity questionnaire (GPAQ): nine country reliability and validity study. J Phys Act Health. 2009;6(6):790–804.
29. Lovibond PF, Lovibond SH. The structure of negative emotional states: comparison of the depression anxiety stress scales (DASS) with the Beck depression and anxiety inventories. Behav Res Ther. 1995;33(3):335–43.
30. Chen B, Wang W, Yang S. The impact of family functioning on depression in college students: a moderated mediation model. J Affect Disord. 2023;340:448–55.
31. Rebar AL, Stanton R, Geard D, Short C, Duncan MJ, Vandelanotte C. A meta-meta-analysis of the effect of physical activity on depression and anxiety in non-clinical adult populations. Health Psychol Rev. 2015;9(3):366–78.
32. Rahman MS, Helgadóttir B, Hallgren M, Forsell Y, Stubbs B, Vancampfort D, Ekblom Ö. Cardiorespiratory fitness and response to exercise treatment in depression. BJPsych Open. 2018;4(5):346–51.
33. Papasavvas T, Bonow RO, Alhashemi M, Micklewright D. Depression symptom severity and cardiorespiratory fitness in healthy and depressed adults: a systematic review and meta-analysis. Sports Med. 2016;46(2):219–30.
34. Snell PG, Mitchell JH. The role of maximal oxygen uptake in exercise performance. Clin Chest Med. 1984;5(1):51–62.
35. Bassett DR Jr, Howley ET. Limiting factors for maximum oxygen uptake and determinants of endurance performance. Med Sci Sports Exerc. 2000;32(1):70–84.
36. Heijnen S, Hommel B, Kibele A, Colzato LS. Neuromodulation of aerobic exercise-a review. Front Psychol. 2016;6:1890.
37. Meeusen R, De Meirleir K. Exercise and brain neurotransmission. Sports Med. 1995;20(3):160–88.
38. Zoladz JA, Pilc A. The effect of physical activity on the brain derived neurotrophic factor: from animal to human studies. J Physiol Pharmacol. 2010;61(5):533–41.
39. Haider S, Khaliq S, Ahmed SP, Haleem DJ. Long-term tryptophan administration enhances cognitive performance and increases 5HT metabolism in the hippocampus of female rats. Amino Acids. 2006;31(4):421–5.
40. Harmer CJ. Serotonin and emotional processing: does it help explain antidepressant drug action? Neuropharmacology. 2008;55(6):1023–8.
41. Patrick RP, Ames BN. Vitamin D and the omega-3 fatty acids control serotonin synthesis and action, part II: relevance for ADHD, bipolar disorder, schizophrenia, and impulsive behavior. FASEB J. 2015;29(6):2207–22.
42. Klein MO, Battagello DS, Cardoso AR, Hauser DN, Bittencourt JC, Correa RG. Dopamine: functions, signaling, and association with neurological diseases. Cell Mol Neurobiol. 2019;39(1):31–59.
43. de Sousa Fernandes MS, Ordônio TF, Santos GCJ, Santos LER, Calazans CT, Gomes DA, Santos TM. Effects of physical exercise on neuroplasticity and brain function: A systematic review in human and animal studies. Neural Plast. 2020;2020:8856621.
44. Lippi G, Mattiuzzi C, Sanchis-Gomar F. Updated overview on interplay between physical exercise, neurotrophins, and cognitive function in humans. J Sport Health Sci. 2020;9(1):74–81.
45. Lavebratt C, Herring MP, Liu JJ, Wei YB, Bossoli D, Hallgren M, Forsell Y. Interleukin-6 and depressive symptom severity in response to physical exercise. Psychiatry Res. 2017;252:270–6.
46. Levine BD. VO2max: what do we know, and what do we still need to know? J Physiol. 2008;586(1):25–34.
47. Scarpellino G, Brunetti V, Berra-Romani R, De Sarro G, Guerra G, Soda T, Moccia F. The unexpected role of the endothelial nitric oxide synthase at the neurovascular unit: beyond the regulation of cerebral blood flow. Int J Mol Sci. 2024;25(16): 9071.
48. Raghuveer G, Hartz J, Lubans DR, Takken T, Wiltz JL, Mietus-Snyder M, Perak AM, Baker-Smith C, Pietris N, Edwards NM, American heart association young hearts athero, hypertension and obesity in the young committee of the Council on lifelong congenital heart disease and heart health in the young. Cardiorespiratory fitness in youth: an important marker of health: A scientific statement from the American Heart Association. Circulation. 2020;142(7):e101-18.
49. Gahche J, Fakhouri T, Carroll DD, Burt VL, Wang CY, Fulton JE. Cardiorespiratory fitness levels among U.S. Youth aged 12–15 years: united states, 1999–2004 and 2012. NCHS Data Brief. 2014;(153):1–8.
50. Murias JM, Kowalchuk JM, Paterson DH. Time course and mechanisms of adaptations in cardiorespiratory fitness with endurance training in older and young men. J Appl Physiol. 2010;108(3):621–7.
51. van Uffelen JG, van Gellecum YR, Burton NW, Peeters G, Heesch KC, Brown WJ. Sitting-time, physical activity, and depressive symptoms in mid-aged women. Am J Prev Med. 2013;45(3):276–81.
52. Huang Y, Li L, Gan Y, Wang C, Jiang H, Cao S, Lu Z. Sedentary behaviors and risk of depression: a meta-analysis of prospective studies. Transl Psychiatry. 2020;10(1):26.

53. Endrighi R, Steptoe A, Hamer M. The effect of experimentally induced sedentariness on mood and psychobiological responses to mental stress. Br J Psychiatry. 2016;208(3):245–51.
54. Henson J, Yates T, Biddle SJ, Edwardson CL, Khunti K, Wilmot EG, Gray LJ, Gorely T, Nimmo MA, Davies MJ. Associations of objectively measured sedentary behaviour and physical activity with markers of cardiometabolic health. Diabetologia. 2013;56(5):1012–20.
55. Wang K, Li Y, Liu H, Zhang T, Luo J. Relationship between different levels of internet use and depressive tendencies in Chinese college students: the chain mediating effect based on physical activity and social adaptability. BMC Psychol. 2024;12(1):670.
56. Edwards MK, Loprinzi PD. Experimentally increasing sedentary behavior results in increased anxiety in an active young adult population. J Affect Disord. 2016;204:166–73.
57. Gielen S, Schuler G, Adams V. Cardiovascular effects of exercise training: molecular mechanisms. Circulation. 2010;122(12):1221–38.
58. Pluim BM, Zwinderman AH, van der Laarse A, van der Wall EE. The athlete's heart: a meta-analysis of cardiac structure and function. Circulation. 2000;101:336–44.
59. Kemi OJ, Haram PM, Loennechen JP, Osnes JB, Skomedal T, Wisløff U, Ellingsen Ø. Moderate vs. high exercise intensity: differential effects on aerobic fitness, cardiomyocyte contractility, and endothelial function. Cardiovasc Res. 2005;67(1):161–72.
60. Hyde JS, Mezulis AH. Gender differences in depression: biological, affective, cognitive, and sociocultural factors. Harv Rev Psychiatry. 2020;28(1):4–13.
61. Colillas-Malet E, Prat G, Espelt A, Juvinyà D. Gender differences in health-related quality of life in people with severe mental illness. PLoS One. 2020;15(2):e0229236.
62. Dahlin J, Härkönen J. Cross-national differences in the gender gap in subjective health in Europe: does country-level gender equality matter? Soc Sci Med. 2013;98:24–8.

Publisher's Note