

A MULTIDIMENSIONAL PATH ANALYSIS OF STRESS-RELIEF FITNESS EXERCISE INTERVENTIONS ON COLLEGE STUDENTS' DEPRESSION BASED ON SEM

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Abstract

To examine the effect of stress-relief fitness exercises on reducing depressive symptoms among college students, and to explore the underlying psychological, physiological, and social support mechanisms. A randomized controlled trial was conducted with 110 college students whose Self-Rating Depression Scale (SDS) scores were ≥ 53 . Participants were randomly assigned to an intervention group ($n=55$) and a control group ($n=55$). The intervention group practiced stress-relief fitness exercises three times per week for 10 weeks, while the control group maintained their usual routine. The SDS, heart rate variability (HRV), and Social Support Rating Scale (SSRS) were used to assess outcomes before and after the intervention. Structural equation modeling (SEM) was employed to analyze the multidimensional intervention pathways. Compared with the control group, the intervention group showed a significant reduction in SDS scores ($p<0.01$), marked improvement in HRV indicators ($p<0.01$), and higher social support scores ($p<0.01$). SEM analysis indicated that psychological regulation was the main intervention pathway, with physiological and social support mechanisms also playing supportive roles. Stress-relief fitness exercises provide an integrated intervention combining psychological, physiological, and social support effects. They can effectively reduce depressive symptoms in college students and are suitable for broader use in campus mental health programs.

Keywords: Stress-relief fitness exercises; College student depression; Exercise intervention; Psycho-physiological-social support mechanism; Structural equation modeling

1.0 INTRODUCTION

Depression has become one of the most common mental health problems among contemporary college students, with prevalence rates rising year by year. It significantly affects students' learning, daily life, and social interactions ^{Error! Reference source not found.}. At present, drug therapy and psychotherapy are the mainstream approaches for depression intervention. However, these methods have notable limitations, such as strong side effects, high economic costs, and poor patient adherence ^{Error! Reference source not found.}. Exercise intervention, as a non-pharmacological approach, is safe, affordable, and easy to promote, and has gradually become a research focus ^{Error! Reference source not found.}. Among them, stress-relief fitness exercise is a systematic intervention that integrates aerobic movement, breathing rhythm training, and emotional regulation. It has unique advantages in improving emotional states and enhancing tolerance to psychological stress ^{Error! Reference source not found.}.

Although previous studies have explored the short-term psychological regulation effects of stress-relief fitness exercises, comprehensive and systematic investigations of their multidimensional mechanisms including psychological, physiological, and social aspects remain limited. In particular, research on their long-term effects and mechanisms among college students is still insufficient^{Error! Reference source not found.}. This study adopts a randomized controlled trial (RCT) and uses structural equation modeling (SEM) to analyze the multidimensional intervention mechanisms of stress-relief fitness exercises on depressive symptoms among college students. The aim is to reveal the interactions among psychological regulation, physiological regulation, and social support, as well as their influence on depressive symptoms. The findings are expected to provide empirical evidence and practical guidance for non-pharmacological interventions for depression.

1. Concepts and Theoretical Foundations

1.1 Depression

Depression is a type of mental disorder characterized mainly by persistent low mood, loss of interest, and impaired cognitive ability^{Error! Reference source not found.}. Among college students, it often manifests as stress from academic demands, difficulties in interpersonal relationships, and crises of self-identity^{Error! Reference source not found.}.

1.2 Stress-Relief Fitness Exercises

This is a comprehensive exercise form that combines aerobic activity, breathing regulation, and psychological relaxation. Through regular physical activity, it helps adjust psychological states and relieve stress^{Error! Reference source not found.}.

1.3 Heart Rate Variability (HRV)

HRV refers to the subtle fluctuations in the intervals between heartbeats (R-R intervals). It is an important indicator for assessing autonomic nervous system regulation and the balance between sympathetic and parasympathetic activity^{Error! Reference source not found.}.

1.4 Social Support

Social support refers to the emotional, informational, and practical assistance an individual receives from social relationships, including family, friends, and other networks. Higher levels of social support are associated with reduced depressive symptoms.

1.5 Theoretical Basis of Multidimensional Intervention

Based on the **Biopsychosocial Model**, this study explores the intervention mechanisms of stress-relief fitness exercises across three dimensions:

- **Psychological Dimension:** Regular exercise promotes the release of endorphins, the body's natural "feel-good" chemicals, which enhance positive emotions and help reduce anxiety and depression^{Error! Reference source not found.}. Exercise also diverts attention from negative emotions, reducing excessive focus on distress. Multiple psychological mechanisms work together to improve depressive symptoms.
- **Physiological Dimension:** Regular physical activity regulates autonomic nervous system function by enhancing parasympathetic activity and increasing HRV, thereby improving physiological stress responses^{Error! Reference source not found.}. Higher HRV indicates better stress tolerance and helps alleviate physical symptoms of depression, such as fatigue, insomnia, and appetite disturbances.
- **Social Dimension:** Group-based fitness exercises enhance interpersonal interaction and emotional exchange, thereby strengthening social support networks^{Error! Reference source not found.}. Shared participation fosters a sense of belonging and emotional support, indirectly easing depressive symptoms. Improved social support not only enhances communication but also strengthens psychological resilience and coping ability.

Structural Equation Modeling (SEM):

SEM is a multivariate statistical method used to test and estimate complex relationships among variables. It integrates the strengths of factor analysis and path analysis, allowing simultaneous handling of multiple dependent and independent variables, and enables deeper analysis of the relationships between latent and observed variables^{Error! Reference source not found.}.

1.6 Research Hypotheses

Drawing on the Biopsychosocial Model and previous studies, this research proposes the following hypotheses:

- **H1:** Stress-relief fitness exercises alleviate depressive symptoms through neurotransmitter regulation and cognitive improvement.
- **H2:** Stress-relief fitness exercises reduce somatic symptoms of depression by improving HRV indicators.
- **H3:** Group-based exercise alleviates depressive symptoms indirectly by enhancing social support.
- **H4:** Psychological, physiological, and social support dimensions have synergistic intervention effects.
- **H5:** The psychological regulation pathway has a significantly stronger effect than the other pathways.

2. RESEARCH SUBJECTS AND METHODS

2.1 Interviews

Following the methodological framework of in-depth interviews, three rounds of interviews were conducted with 10 experts from five universities, including Beijing Sport University, Fujian Normal University, Fujian University of Traditional Chinese Medicine, Jimei University, and Fujian University of Technology. The interviews helped generate innovative ideas and establish theoretical foundations, ensuring the scientific validity and effectiveness of exercise design and training methods, with the goal of optimizing fitness outcomes.

2.2 Questionnaires

2.2.1 Questionnaires were distributed to the above experts to understand the current development and trends in stress-relief fitness exercise routines and to collect their opinions on the rationality of exercise design, practice methods, and workload arrangements. A total of 10 questionnaires were distributed and all were collected on-site, achieving a 100% response and validity rate.

2.2.2 To further ensure that the design of the stress-relief fitness exercises was reasonable, practical, and effective, six experts in aerobics, two experts in sports training, and two experts in sports psychology were consulted in multiple rounds. Qualitative analysis was used to evaluate the content of the program. More than half of the experts gave positive feedback regarding the rationality of movement sequencing and workload settings, and no unreasonable comments were reported. This indicated that the designed fitness exercise routine followed the basic principles of physical training and met scientific standards.

2.3 Structural Equation Modeling (SEM)

Structural Equation Modeling (SEM) was used to analyze the multidimensional intervention mechanisms of stress-relief fitness exercises on depressive symptoms in college students. Reliability and validity were tested using $CR \geq 0.7$, $AVE \geq 0.5$, and $HTMT \leq 0.85$ as benchmarks. Confidence intervals were calculated through 500 bootstrap samples. Latent variables included psychological regulation, physiological regulation, and social support mechanisms, while observed variables included SDS scores, HRV indicators, and SSRS scores. The model assumed that all three dimensions contributed significantly to alleviating depressive symptoms and interacted with one another. AMOS software was applied to test model fit and perform path analysis, evaluating both the model's overall fit and the significance of path coefficients.

3. EXPERIMENTAL PROCEDURES AND METHODS

3.1 Research Design

This study adopted a randomized controlled trial (RCT) to ensure scientific rigor and feasibility. The intervention lasted for 10 weeks. During this period, the intervention group received the specific exercise program, while the control group maintained their usual routines. Data from both groups were compared to evaluate the actual effectiveness of the intervention.

3.2 Participants

A total of 110 college students with depressive symptoms were recruited from Fujian Agriculture and Forestry

University through voluntary registration combined with psychological screening. Participants were informed in detail about the purpose, procedures, schedule, potential risks, and benefits of the study. Written informed consent was obtained from all participants. To ensure data privacy and participant rights, coded identifiers (Group A, Group B) were used instead of real names. All questionnaire data and HRV physiological measurements were anonymized and managed by independent assistants. Data were restricted to use by the project team's core members for research purposes only and were either destroyed or anonymized after the study.

Inclusion criteria required participants to have an SDS score ≥ 53 . The 110 students were randomly assigned into an intervention group ($n = 55$) and a control group ($n = 55$). Baseline equivalence tests showed no statistically significant differences between the two groups in gender, age, or depression severity ($p > 0.05$) (see Table 1).

Table 1. Baseline Characteristics of Participants ($n = 110$)

Group	n	Gender		Age (years, M $\pm$ SD)	SDS Standard Score (M $\pm$ SD)
		Male	Female		
Intervention	55	26	29	20.31 $\pm$ 1.51	58.25 $\pm$ 5.15
Control	55	27	28	20.45 $\pm$ 1.48	57.80 $\pm$ 5.02
<i>t</i>				0.48	0.42
<i>p</i>				0.63	0.67

3.3 Intervention Program

3.3.1 Intervention Group: Participants in the intervention group underwent a 10-week program, exercising three times per week. Each session was scheduled from 18:00 to 19:00, lasting 60 minutes, and included three phases: 10 minutes of warm-up, 40 minutes of core training, and 10 minutes of cool-down.

3.3.2 Control Group: Participants in the control group maintained their usual daily routines without any intervention.

3.3.3 Specific Content: The stress-relief fitness exercise program integrated elements from modern aerobics, cheerleading, street dance, Latin dance, martial arts, yoga, traditional Chinese massage, strength training, and relaxation techniques. The core objective was to combine these diverse components to reduce stress, improve emotional states, and promote overall physical and mental health (see Table 2).

Table 2. Main Components of the Stress-Relief Fitness Exercise Program

Item	Content	Track Title	Time (min)	Tempo
Modern Aerobics	Combines aerobic fitness moves with dance steps, emphasizing overall coordination and improved cardiopulmonary function	<i>Happy Worship</i>	2.3	Fast
Cheerleading Aerobics	Focuses on cheerleading hand positions, steps, and movements; energetic and team-oriented	<i>Joyful Feeling</i>	3.6	Fast
Street Dance Aerobics	Incorporates street dance elements; free and personalized movements with focus on rhythm and body control	<i>Zhuque</i>	4.1	Medium –Fast
Latin Aerobics	Uses hip twists, arm swings, and other Latin dance moves; passionate and lively, emphasizing waist and abdomen flexibility	<i>Despacito (Remix)</i>	3.8	Medium –Fast

Resistance Band Aerobics	Uses resistance bands for full-body and targeted strength training; improves muscle power and endurance	<i>Herbal Classic</i>	3.48	Medium
Traditional Chinese Massage Aerobics	Incorporates TCM massage methods (pressing, tapping, stretching) to promote circulation and relaxation	<i>Past and Present Life (Piano Version)</i>	5.25	Slow
Tai Chi Aerobics	Based on Tai Chi movements; emphasizes breathing–movement coordination, relaxation, and balance	<i>Cloud Palace Rapid Sound – Black Myth Wukong Version</i>	2.83	Slow
Yoga Relaxation Aerobics	Combines yoga postures with breathing exercises; relaxes muscles, reduces stress, enhances flexibility and focus	<i>Earth Song</i>	5.77	Slow
Core Strength Aerobics	Focuses on abdominal, back, and pelvic muscles; strengthens core stability and body control	<i>My Future Tense</i>	3.27	Medium

Note: The tempos are classified as fast (140–160 BPM/min), medium–fast (120–140 BPM/min), medium (100–120 BPM/min), and slow (60–100 BPM/min), reflecting exercise intensity and speed.

3.3.4 Warm-up and Cool-down

In the intervention group, the warm-up and cool-down phases adopted a low-intensity exercise mode, while the core part mainly used a moderate-intensity mode. Exercise intensity was regulated using heart rate monitoring. The target heart rate range for moderate-intensity exercise was set at 65%–75% of maximum heart rate (i.e., 135–150 bpm), and for low-intensity exercise at 55%–65% (i.e., 105–120 bpm). Six to eight participants were randomly selected, and 10 instant heart rate data points were evenly recorded during exercise to ensure the intensity met the preset standards (see Table 3).

3.3.5 Implementation

Professional instructors guided the sessions to ensure accurate movements and appropriate exercise load. The training plan was progressive, allowing participants' physical fitness to improve gradually.

To ensure both effectiveness and adaptability, a 10-week intervention was structured with periodic adjustments:

- **Weeks 1–2 (Adaptation Phase):** Focused on low-to-moderate intensity, emphasizing correct movement execution and rhythm awareness.
- **Weeks 3–8 (Strengthening Phase):** Gradually increased movement complexity and rhythm speed, with a greater proportion of core strength training.
- **Weeks 9–10 (Consolidation and Optimization Phase):** Maintained moderate intensity while introducing highly coordinated movements to increase engagement and challenge.

For **load adjustment**, instructors collected weekly feedback from participants regarding exercise intensity, fatigue, and psychological well-being (using the Borg Rating of Perceived Exertion and a short mood assessment scale). Combined with heart rate monitoring results, training intensity and tempo distribution were dynamically fine-tuned to avoid overload or insufficient stimulation, ensuring the intervention achieved optimal effects within safe limits.

3.3.6 Blinding Measures

This study adopted a single-blind design. Intervention instructors could not be blinded since they needed to know

the movement content and procedures. However, all outcome assessors (responsible for SDS, HRV, and SSRS questionnaire distribution, collection, and data processing) remained blinded to participant groupings, using only codes (Group A, Group B) for scoring and data entry. This minimized evaluation bias to the greatest extent possible.

Table 3. Exercise Intervention Program

	Monday	Wednesday	Friday
Duration (min/session)	60		
Exercise Intensity	55%-75%HR _{max}		
Intervention Content and Time Allocation	1) Warm-up (5–10 min): Basic fitness steps; dynamic stretches for neck, shoulders, waist, hips, knees, and ankles in street-dance style. 2) Core (35–40 min): Modern fitness exercise, cheerleading, street dance fitness, Latin fitness, resistance band training, and core strength training. 3) Cool-down (5–10 min): Traditional Chinese massage fitness exercise, Tai Chi fitness exercise.	1) Warm-up (5–10 min): Basic fitness steps; dynamic stretches for neck, shoulders, waist, hips, knees, and ankles in street-dance style. 2) Core (35–40 min): Modern fitness exercise, cheerleading, street dance fitness, Latin fitness, resistance band training, and core strength training. 3) Cool-down (5–10 min): Traditional Chinese massage fitness exercise, Yoga relaxation exercise.	1) Warm-up (5–10 min): Basic fitness steps; dynamic stretches for neck, shoulders, waist, hips, knees, and ankles in street-dance style. 2) Core (35–40 min): Modern fitness exercise, cheerleading, street dance fitness, Latin fitness, resistance band training, and core strength training. 3) Cool-down (5–10 min): Traditional Chinese massage fitness exercise, Tai Chi fitness exercise.

3.4 Measurement Tools and Testing Methods

Depressive Symptoms: Depressive symptoms were assessed using the Self-Rating Depression Scale (SDS). The scale consists of 20 items covering four domains: affective, somatic, psychomotor, and psychological disturbance. It provides a systematic quantitative evaluation of depressive symptoms, with standardized scores ranging from 25 to 100. Lower scores indicate milder depressive symptoms and better mental health status^{Error! Reference source not found.}. Reliability indices showed Cronbach's $\alpha = 0.88$ and test–retest reliability $r = 0.82$. The criterion validity between the Chinese version of the SDS and the Hamilton Depression Rating Scale (HAMD) was $r = 0.75$, indicating strong consistency in discriminating depressive symptoms. Exploratory factor analysis extracted two main factors, explaining 54.6% of the variance, confirming its suitability for depression screening and evaluation among Chinese populations.

Physiological Indicators: Autonomic nervous function was assessed through heart rate variability (HRV) analysis. HRV data were collected using the Polar H10 heart rate monitor, with participants wearing the device in a quiet seated position for 5–10 minutes to capture stable R–R interval data. Higher HRV values indicate stronger autonomic regulation and lower physiological stress responses, while lower HRV values suggest weaker regulation and higher stress levels^{Error! Reference source not found.}. The Polar H10 has been validated against the standard 3-lead electrocardiogram, with Pearson correlation coefficients for R–R intervals ranging from $r = 0.98$ – 0.99 . Errors in HRV indices such as RMSSD and SDNN were within 5 ms, demonstrating strong criterion validity and measurement consistency, making it appropriate for short-term resting HRV assessment.

Social Support: Social support was evaluated using the Social Support Rating Scale (SSRS), developed by Xiao Shuiyuan in 1986. The scale consists of 12 items across three dimensions: (1) objective support (4 items), referring

to tangible resources received; (2) subjective support (4 items), reflecting perceived support; and (3) support utilization (4 items), measuring the ability to actively use available support. Items are rated on a 1–4 scale, with total scores ranging from 12 to 66. Higher scores indicate higher levels of social support^{Error! Reference source not found.}. The SSRS demonstrates strong reliability (overall Cronbach’s $\alpha = 0.91$; subscales $\alpha = 0.78$ – 0.85) and criterion validity (correlation with mental health-related scales $r = 0.74$), confirming its suitability for measuring both perceived and actual social support in the Chinese population.

Table 4. Data Quality Control

Control Aspect	Method	Standard
Questionnaire Data	Two assistants enter data independently and cross-check	Randomly recheck 10% of samples
HRV Data	Exclude HR < 40 bpm or > 180 bpm; apply 5 Hz low-pass filter + 50 Hz notch filter; Kubios automatic detection with manual verification	Data accuracy ensured through dual filtering and expert review
Overall Management	Save raw data with coding (Groups A, B); independent assistant compiles and decodes; check for missing and abnormal values	Maintain confidentiality and ensure data integrity

3.5 Data Analysis

Many previous studies consistently suggest that exercise interventions only reduce depressive symptoms in a unidirectional manner, with no evidence of interventions leading to an increase in depression scores^{Error! Reference source not found.}. Given the clear directional hypothesis that the intervention group would show better psychological, physiological, and social support outcomes than the control group after the intervention a one-tailed test was used for statistical analysis. This approach increases the sensitivity of detecting effects in the expected direction. Unless otherwise specified, all hypothesis testing was conducted at a significance level of $\alpha = 0.05$, with one-tailed criteria applied. Data analysis was performed using SPSS 26.0 and Amos 24.0. All results are presented as mean $\pm$ standard deviation (M $\pm$ SD).

4 RESULTS AND ANALYSIS

4.1 Changes in Depressive Symptoms Before and After the Intervention

Statistical analysis showed no significant difference between the two groups at baseline (intervention group: 58.25 ± 5.15 ; control group: 57.80 ± 5.02 ; $t = 0.44$, $p = 0.66$), indicating comparable initial levels. After 10 consecutive weeks of stress-reducing fitness exercises, the intervention group showed a significant improvement in depressive symptoms, with SDS scores decreasing markedly from 58.25 ± 5.15 to 42.05 ± 4.80 ($t = 15.80$, $p < 0.01$). The control group also showed a slight reduction, from 57.80 ± 5.02 to 56.10 ± 5.08 , but the change was marginal and did not reach clear statistical significance ($t = 1.58$, $p = 0.06$). Between-group comparisons further confirmed the significance of the intervention effect ($t = 13.78$, $p < 0.01$).

Clearly, stress-reducing fitness exercises, as a multidimensional non-pharmacological intervention, improved participants’ emotional regulation, self-efficacy, and attention-shifting mechanisms, thereby significantly reducing depressive symptoms among college students. The intervention group outperformed the control group, demonstrating that this method is effective and practical for promoting mental health in college populations. The intervention plan of stress-reducing fitness exercises had a significant effect on alleviating depressive symptoms (see Table 5).

Table 5. Comparison of Depressive Symptoms Between the Two Groups (M ± SD)

Group	N	Pre-intervention (Standard Score)	Post-intervention (Standard Score)	<i>t</i>	<i>p</i>
Intervention	55	58.25±5.15	42.05±4.80	15.80	<0.01
Control	55	57.80±5.02	56.10±5.08	1.58	0.06
Post-intervention comparison between groups				13.78	<0.01

4.2 Comparative Analysis of Changes in Autonomic Nervous Function

Changes in autonomic nervous system function were assessed using heart rate variability (HRV) indices. At baseline, the HRV values of the intervention group and the control group were 45.15 ± 6.05 and 44.80 ± 5.90 , respectively. Statistical testing showed no significant difference between the two groups ($t = 0.31$, $p = 0.76$), indicating good consistency and comparability of their initial physiological states.

After 10 weeks of stress-relief fitness exercise intervention, the HRV in the intervention group significantly increased to 62.30 ± 5.78 , with a highly significant pre–post difference ($t = -15.20$, $p < 0.01$). In contrast, the control group showed only a slight increase to 46.08 ± 6.00 , which was not statistically significant ($t = -1.25$, $p = 0.21$).

Between-group analysis after the intervention further confirmed that HRV values in the intervention group were significantly higher than those in the control group ($t = 13.80$, $p < 0.01$). This indicates that stress-relief fitness exercises effectively improved autonomic nervous function in college students. From a physiological perspective, this positive change may be attributed to enhanced parasympathetic activity and improved balance between sympathetic and parasympathetic nervous regulation, thereby reducing physiological stress responses. Such improvement not only reflects enhanced adaptability to external stressors but also provides a physiological basis for the effectiveness of stress-relief fitness exercise as a non-pharmacological intervention for depressive symptoms. (See Table 6)

Table 6. Comparison of HRV Indicators Between the Two Groups (M ± SD)

Group	N	Pre-intervention (score)	Post-intervention (score)	<i>t</i>	<i>p</i>
Intervention	55	45.15±6.05	62.30±5.78	-14.90	<0.01
Control	55	44.80±5.90	46.08±6.00	-1.25	0.21
Baseline comparison				0.31	0.76
Post-intervention comparison				13.80	<0.01

4.3 Comparison of Changes in Social Support Levels Between the Two Groups Before and After the Intervention

Statistical results showed that before the intervention, the total social support scores of the intervention group and the control group were 32.55 ± 4.10 and 33.05 ± 4.00 , respectively. The difference between the two groups was not statistically significant ($t = -0.62$, $p = 0.53$), indicating that the baseline levels of social support were comparable.

After 10 weeks of stress-reduction fitness exercise, the intervention group's social support score significantly

increased to 45.60 ± 3.90 , showing a highly significant difference compared with the pre-intervention level ($t = -17.30, p < 0.01$). In contrast, the control group, which did not undergo intervention, only showed a slight increase to 34.25 ± 4.15 , and this change was not statistically significant ($t = -1.50, p = 0.14$).

Further intergroup comparison revealed that after the intervention, the social support score of the intervention group was significantly higher than that of the control group ($t = 14.50, p < 0.01$). These findings clearly demonstrate that the group-based form of stress-reduction fitness exercises enhanced interaction opportunities, emotional exchange, and social connectedness among college students, thereby significantly improving their social support levels. The improvement was markedly better than in the control group, providing solid empirical support for stress-reduction fitness exercises in alleviating depressive symptoms through the reinforcement of social support mechanisms. (See Table 7).

Table 7. Comparison of Social Support Levels Between the Two Groups (M $\pm$ SD)

Group	N	Pre-intervention (score)	Post-intervention (score)	<i>t</i>	<i>p</i>
Intervention	55	32.55 $\pm$ 4.10	45.60 $\pm$ 3.90	-17.30	<0.01
Control	55	33.05 $\pm$ 4.00	34.25 $\pm$ 4.15	-1.50	0.14
Baseline comparison				-0.62	0.53
Post-intervention comparison				14.50	<0.01

4.4 Multidimensional Analysis of the Intervention Mechanisms

Based on multiple regression analysis, the multidimensional mechanisms through which stress-reduction fitness exercises alleviate depressive symptoms in college students were examined, covering three dimensions: psychological regulation, physiological regulation, and social support.

The results showed that all three mechanisms significantly contributed to the improvement of depressive symptoms, with regression coefficients $\beta = -0.44$, $\beta = -0.31$, and $\beta = -0.27$, respectively (all $p < 0.01$). This indicates that each variable had a significant explanatory effect on changes in depression scores. Among them, the absolute value of the psychological regulation coefficient was the largest, suggesting that it played the most critical role in the overall intervention effect.

This mechanism may act through pathways such as neurotransmitter regulation, increased endorphin secretion, and attentional shift induced by regular exercise, thereby positively influencing negative emotions. On the physiological level, enhanced parasympathetic activity and improved heart rate variability (HRV) mitigated chronic stress responses. Regarding social support, participation in group-based stress-reduction fitness exercises increased interpersonal interactions, strengthened belongingness, and provided emotional support, thereby improving the ability to cope with social stress.

The multiple regression analysis further confirmed that while the three mechanisms function independently, they also interact with each other, jointly forming an integrated whole. This reveals that the underlying mechanism of stress-reduction fitness exercise interventions for alleviating depressive symptoms reflects the composite features of a biopsychosocial model. (See Table 8)

Table 8. Results of Multiple Regression Analysis: Effects of Psychological, Physiological, and Social Support Mechanisms on Depressive Symptoms

Variable	(β)	(SE)	<i>t</i>	<i>p</i>	95% CI
Psychological mechanism	-0.44	0.08	-5.63	<0.01	-0.61,-0.29

Variable	(β)	(SE)	t	p	95% CI
Physiological mechanism	-0.31	0.07	-4.57	<0.01	-0.46,-0.18
Social support mechanism	-0.27	0.06	-4.67	<0.01	-0.40,-0.16

4.4.1 Psychological Regulation Mechanism

From a psychological perspective, stress-reduction fitness exercises significantly alleviate depressive emotions among college students through multiple synergistic processes. Regular physical activity can activate the endogenous opioid system, particularly by promoting the release of neurotransmitters such as endorphins, which have natural analgesic and mood-enhancing effects, thereby improving emotional states on a biochemical level^{Error! Reference source not found.}. During exercise, attention shifts from internal negative emotions to body movements and rhythmic music, creating a cognitive redirection that reduces sustained focus on negative emotions. This diminishes negative cognitive processing and effectively interrupts the persistent cycle of depressive mood^{Error! Reference source not found.}. The choreographed and rhythmic design of stress-reduction fitness exercises also presents moderate challenges. As participants become more proficient, they gradually develop confidence in their physical abilities, thereby enhancing self-efficacy. Such positive self-appraisal plays a vital role in stress management and emotional regulation.

The intervention does not rely on a single psychological pathway but operates through an integrated process of “physiological arousal, emotional transformation, cognitive reconstruction,” forming a positive feedback loop that strengthens psychological resilience. Thus, from the psychological dimension, stress-reduction fitness exercises not only improve current emotional states but also foster deeper changes in cognitive structures and emotional regulation patterns, providing an important pathway for promoting college students’ mental health.

4.4.2 Physiological Regulation Mechanism

On the physiological level, the key contribution of stress-reduction fitness exercises to alleviating depressive symptoms lies in optimizing autonomic nervous system function. As a form of moderate-intensity aerobic activity, these exercises effectively activate parasympathetic nervous activity while suppressing excessive sympathetic arousal, thereby promoting improved heart rate variability (HRV). HRV, an important indicator of autonomic function, reflects the body’s adaptive and stress-regulation capacity. Increases in HRV suggest enhanced resilience to stress. Low HRV levels are strongly associated with emotional disorders and chronic stress responses, while exercise interventions can significantly reverse these adverse physiological states.

Through sustained exercise, participants achieve synchronized regulation of respiratory rhythms, which helps modulate vagal activity and enhance autonomic balance^{Error! Reference source not found.}. Additionally, exercise-induced physiological changes such as elevated body temperature and improved blood circulation may strengthen central nervous system regulation of emotions and help relieve somatic symptoms linked with depression, including insomnia, chronic fatigue, and reduced appetite^{Error! Reference source not found.}.

By improving cardiopulmonary endurance, balancing autonomic activity, and stabilizing physiological rhythms, stress-reduction fitness exercises establish a solid physiological foundation that supports the alleviation of depressive symptoms.

4.4.3 Social Support Mechanism

From a social-psychological perspective, stress-reduction fitness exercises also play a crucial role in enhancing social support mechanisms, which in turn contribute to the alleviation of depressive symptoms in college students. Conducted in group settings, the exercises create frequent opportunities for interpersonal interaction through cooperative practice and collective engagement. During ongoing participation, students establish emotional bonds and mutual support in dimensions such as movement coordination, rhythm synchronization, and expressive

communication, thereby strengthening their sense of belonging and social connectedness^{Error! Reference source not found.}.

Research has shown that higher levels of social support not only reduce feelings of loneliness and isolation but also significantly enhance emotional stability and stress resistance. The group-based environment of stress-reduction fitness exercises encourages participants to provide mutual encouragement and positive feedback, indirectly boosting psychological safety and resilience against adverse experiences^{Error! Reference source not found.}.

Through shared experiences of group belonging, individuals become more willing to express emotions, gain recognition and understanding, and break free from emotional suppression, leading to positive cycles of interpersonal interaction. This intervention goes beyond emotional regulation, fostering the construction and reinforcement of social support networks, thereby providing effective social resources for maintaining college students' mental health.

To further verify whether the psychological regulation mechanism is significantly stronger than the other mechanisms, the Bootstrap method (1,000 resamples) was used to compare differences in regression coefficients. Results showed: the difference between psychological and physiological mechanisms was -0.13 (95% CI: -0.22, -0.04), $p=0.012$; the difference between psychological and social support mechanisms was -0.17 (95% CI: -0.28, -0.06), $p=0.003$. This indicates that the effect of the psychological regulation mechanism on alleviating depressive symptoms is significantly stronger than that of physiological and social support mechanisms, supporting Hypothesis H5.

4.5 Structural Equation Model Analysis

Based on the constructed structural equation model (SEM), AMOS software was used for model fitting and path analysis. The model fit indices were: $\chi^2/df = 2.20$, CFI = 0.95, TLI = 0.93, RMSEA = 0.06, SRMR = 0.04, indicating a good overall model fit with strong explanatory power and theoretical suitability.

In terms of path relationships, psychological regulation, physiological regulation, and social support mechanisms all showed significant negative effects on depressive symptoms through standardized path coefficients, and all three reached statistical significance ($p < 0.01$). This confirms that these three latent variables play a synergistic role in alleviating depression.

Among them, the psychological regulation mechanism had the strongest path coefficient, suggesting it is the most significant factor in the intervention pathway. This mechanism influences depressive manifestations such as low mood, loss of interest, and cognitive decline indirectly through the observed variables: endorphin release, attentional shift, and enhancement of self-efficacy. The physiological mechanism functions through HRV indicators and improvements in parasympathetic activity, reducing chronic stress responses physiologically, and thereby impacting the biological basis of depression. The social support mechanism, represented by interpersonal interaction frequency and sense of social connectedness, was significantly related to enhanced emotion regulation and improved resilience to negative social events.

The causal paths between observed variables and latent variables were theoretically grounded, and error terms were reasonably controlled, demonstrating that the SEM model is not only structurally sound but also effectively reflects the multidimensional mechanisms of stress-relief fitness exercise in alleviating depression among college students. The path diagram clearly illustrates how the intervention acts on depressive symptoms through psychological, physiological, and social dimensions, providing scientific decision-making support for mental health interventions in higher education.

The application of SEM provides a robust quantitative basis for the integrated understanding and empirical validation of intervention mechanisms, confirming the rationality of the multidimensional pathways and the stability of the mechanisms. (See Table 9)

Table 9 Relationship between latent variables, observed variables, error terms and model fitting indicators

Classification	Variable	Incidence relation
Latent variables	Psychological regulation mechanism (A)	Impact on depressive symptoms(D)
	Physiological regulation Mechanisms (B)	Impact on depressive symptoms (D)

Classification	Variable	Incidence relation
	Social support mechanisms (C)	Impact on depressive symptoms (D)
Observable variable	Endorphin release (A1)	It belongs to the psychological regulation mechanism (A)
	Attention diversion (A2)	It belongs to the psychological regulation mechanism (A)
	Affect the improvement of self-efficacy (A3)	It belongs to the psychological regulation mechanism (A)
	HRV Metric (B1)	It belongs to physiological regulation mechanism(B)
	Vice sympathetic activity (B2)	It belongs to physiological regulation mechanism(B)
	Interpersonal interaction (C1)	It belongs to the social support mechanism(C)
	Social connections (C2)	It belongs to the social support mechanism (C)
	Be down in spirits (D1)	It's a symptom of depression (D)
	hebetude (D2)	It's a symptom of depression (D)
	Decline in cognitive function (D3)	It's a symptom of depression (D)
Error term	e1	It's a symptom of depression (A1)
	e2	Affecting attentional shifts (A2)
	e3	Self-efficacy improved (A3)
	e4	Affecting HRV indicators (B1)
	e5	Affects parasympathetic activity (B2)
	e6	Affecting interpersonal interactions (C1)
	e7	Impact on social bonding (C2)
	e8	Affecting low mood(D1)
	e9	Impact of loss of interest (D2)
	e10	Affect cognitive decline (D3)
Model fitting index	$\chi^2/df = 2.20$	Model fitting goodness index
	CFI = 0.95	Comparative fitting indices
	TLI = 0.93	Tucker-Lewis index
	RMSEA = 0.06	Approximate error root mean square
	SRMR = 0.04	Root mean square of standardized residuals

Reliability and Validity Tests

- **Convergent validity:** All latent variables had composite reliability (CR) > 0.8 and AVE > 0.5 (psychological = 0.52, physiological = 0.61, social support = 0.55), meeting Fornell & Larcker standards (see Table 10).
- **Discriminant validity:** The square root of each latent variable's AVE (bold diagonal values) was greater than its correlation coefficients with other latent variables (lower triangle). HTMT ratios were all < 0.85, indicating good discriminant validity among the three dimensions (see Table 11).
- **Collinearity control:** MSV < AVE and ASV < AVE, confirming no excessive collinearity among latent variables.

Table 10. Reliability and Validity Test Results of Latent Variables (M±SD)

Latent	CR	AVE	MSV	ASV
Psychological Mechanism	0.89	0.52	0.36	0.31
Physiological Mechanism	0.86	0.61	0.28	0.25
Social Support Mechanis	0.82	0.55	0.24	0.22

Note: CR = Composite Reliability, AVE = Average Variance Extracted, MSV = Maximum Shared Variance, ASV = Average Shared Variance

Table 11. Discriminant Validity Test (Comparison of AVE Square Root and Correlation Coefficients)

	Psychological Mechanism	Physiological Mechanism	Social Support Mechanism
Psychological Mechanism	0.72	0.45	0.38
Physiological Mechanism	0.45	0.78	0.42
Social Support Mechanism	0.38	0.42	0.74

The results of the model path analysis show that the negative predictive effect of the **psychological regulation mechanism** on depressive symptoms is the strongest ($\beta = -0.45$). The effects of the physiological and social support mechanisms are -0.32 and -0.28 , respectively, all reaching a significant level ($p < 0.01$). Using parameter constraint testing in AMOS (Model Comparison), when the path coefficients of the psychological and physiological mechanisms were constrained to be equal, the model fit deteriorated significantly ($\Delta\chi^2 = 6.84$, $p = 0.009$), confirming that the psychological mechanism has the stronger path effect (see Table 12).

Table 12. Path Analysis Results of SEM for the Stress-Relief Fitness Exercise Intervention Mechanism (Standardized Path Coefficients).

Path Direction	Standardized Coefficient β	Path	Significance p-value
A Psychological Regulation Mechanism → D Depressive Symptoms	-0.75		< 0.01
B Physiological Regulation Mechanism → D Depressive Symptoms	-0.45		< 0.01
C Social Support Mechanism → D Depressive Symptoms	-0.32		< 0.01
A → A1 Endorphin Release	0.67		< 0.01
A → A2 Attention Shift	0.71		< 0.01
A → A3 Self-Efficacy	0.65		< 0.01
B → B1 HRV Indicators	0.72		< 0.01
B → B2 Parasympathetic Nervous Activity	0.68		< 0.01
C → C1 Interpersonal Interaction Frequency	0.74		< 0.01
C → C2 Sense of Social Connectedness	0.77		< 0.01
D → D1 Low Mood	0.81		< 0.01
D → D2 Loss of Interest	0.78		< 0.01
D → D3 Cognitive Decline	0.69		< 0.01

Note: All path coefficients are standardized coefficients based on SEM analysis. Data are derived from AMOS 24.0 software output.

The associations between observed variables and latent variables show rationality and validity, accurately reflecting the content and logical relationships of the theoretical framework. The path diagram illustrates the multidimensional intervention pathways, offering practical guidance. (See Figure 1).

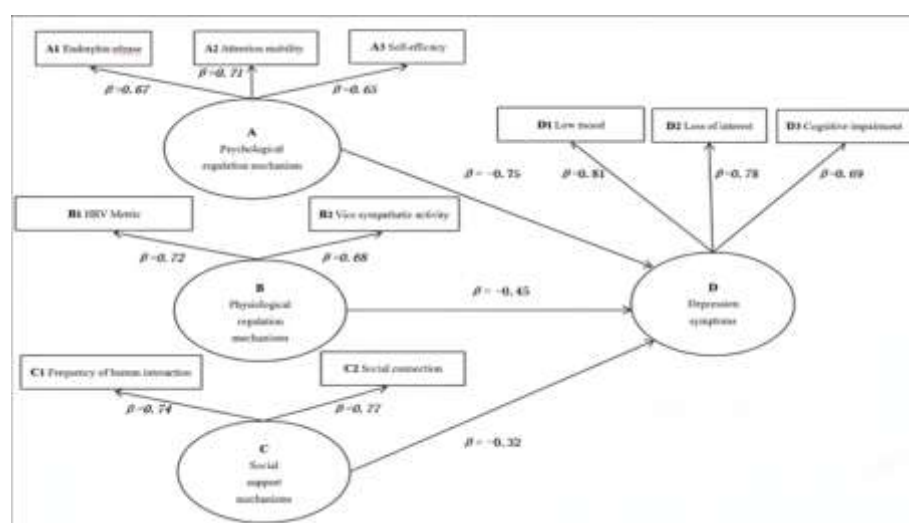


Figure 1. Structural Equation Model Path Diagram of the Stress-Relief Fitness Exercise Intervention Mechanism
Note: The path coefficients (β) in Figure 1 are standardized coefficients derived from SEM modeling results. All significance levels reached $p < 0.01$. Arrows indicate the direction of causal relationships, and the thickness of the paths corresponds to the magnitude of influence.

To verify the rationality and statistical independence of the model structure, this study conducted a systematic analysis of the modification indices (MI) of the SEM and examined collinearity among variables (see Table 13). All latent and observed variable MIs were below the common threshold (10), meaning no additional paths or residual covariances were required. The maximum variance inflation factor (VIF) among variables was 1.89, indicating no risk of multicollinearity. These results further ensure the scientific rigor and interpretability of the model.

Table 13. Modification Indices and Collinearity Test Results of the SEM

Test Item	Indicator Name	Result	Reference Threshold	Statistical Conclusion
Modification Indices (MI)	Maximum MI (MImax)	7.30	< 10	No additional paths needed
	Highest MI among error terms	6.50	< 10	No high covariance among errors
Collinearity Test	Latent Variable VIF (highest)	1.72	< 5	No multicollinearity risk
	Observed Variable VIF (highest)	1.89	< 5	Independent contributions clear

Note: The data in this table are derived from the output of Structural Equation Modeling (SEM). Model fitting and path analysis were conducted using AMOS 24.0 software.

5. DISCUSSION

This study demonstrates that a 10-week stress-relief fitness exercise program (three sessions per week, 60 minutes each) can significantly reduce Self-Rating Depression Scale (SDS) scores, improve heart rate variability (HRV) indicators, and enhance social support among college students. Psychological, physiological, and social mechanisms jointly contributed to alleviating depressive symptoms. Aerobic exercise promotes the secretion of endorphins, which helps relieve depressive emotions and reduce feelings of distress ^{Error! Reference source not found.}. This mechanism was confirmed in the present study, and the multidimensional analysis highlights the unique role of

stress-relief fitness exercise in mitigating depressive symptoms.

Improvements in cardiopulmonary function were effectively achieved through this aerobic form of exercise, accompanied by enhanced glycogen metabolism and optimized cerebral blood circulation, which helped eliminate fatigue. The rhythm and melody of the accompanying music further contributed to emotional regulation, heightened the sense of pleasure during exercise, and improved nervous system activation, collectively resulting in relief from depressive symptoms^{Error! Reference source not found.}. By regulating autonomic nervous system function, the intervention increased parasympathetic activity and improved HRV, reducing physiological stress responses and alleviating somatic symptoms associated with depression^[24].

Regular participation in fitness exercise is also beneficial for weight management, body shape optimization, and posture correction among college students. Enhanced self-image and personal temperament foster improved self-confidence and increased self-efficacy, which in turn relieve depression related to poor self-perception^{Error! Reference source not found.}. The group-based nature of stress-relief fitness exercise provided a platform for communication, emotional expression, and the reduction of interpersonal barriers. Psychological obstacles were reduced through diverse exercise forms, while a positive and cohesive atmosphere encouraged emotional exchange during interactions. The sense of belonging fostered by cooperation and mutual encouragement contributed to emotional support, helping maintain positive emotions and reduce depressive symptoms^{Error! Reference source not found.}. The enhancement of social support was evident in improved interpersonal relationships and strengthened psychological resilience^{Error! Reference source not found.}. This contributed to better coping with life stress and challenges. Thus, stress-relief fitness exercise, combining unique physical activity with group interaction, is well-suited to the psychological and physiological characteristics of college students.

The social support mechanism was also found to significantly reduce depressive symptoms ($\beta = -0.28$, $p < 0.01$). Measurements with the SSRS scale showed significant improvements in objective support (practical help received during group activities), subjective support (enhanced sense of emotional recognition), and support utilization (greater awareness of actively seeking help) in the intervention group ($p < 0.05$), validating the hypothesis that group-based exercise exerts effects through multidimensional social support.

Consistent with Hypothesis H5, the psychological regulation mechanism via endorphin release and attentional shift showed a stronger effect on alleviating depressive symptoms than the physiological and social support mechanisms, highlighting the central role of cognitive-emotional intervention.

As the intervention instructors were required to participate fully in teaching the stress-relief fitness program, blinding was not feasible; only outcome assessors were blinded (single-blind). While this reduced measurement and recording bias, performance bias may still exist. Future studies could adopt double-blind designs, for example by using video-based remote guidance or outsourcing interventions to third-party institutions, thereby improving internal validity.

The multidimensional intervention model shows significant potential for broader application. The intervention program in this study was systematic, structured, and operable, making it suitable for implementation in universities, communities, and mental health institutions. With the growing use of digital health technologies and wearable devices, future work could explore integrated “online + offline” models or combined approaches such as “exercise + social support + emotional self-help” to achieve wider population coverage and long-term monitoring. This would facilitate the normalization and personalization of multidimensional interventions on a larger scale.

6. CONCLUSION

This study used multidimensional indicators to validate the effects and mechanisms of stress-relief fitness exercise on depressive symptoms in college students. Results showed that stress-relief fitness exercise significantly alleviated depression by improving psychological regulation, optimizing physiological function, and strengthening social support networks. With its fashionable, simple, and easily promoted characteristics, stress-

relief fitness exercise is well-suited for dissemination in group settings such as campuses and communities. The intervention not only showed short-term effectiveness but also contributed to the development of positive lifestyles and emotional regulation patterns. Its structured and sustained features provide students with systematic and operable pathways for psychological support. Future research should further investigate the long-term intervention effects and the stability of its mechanisms to provide more universally applicable strategies for depression prevention and intervention. In addition, stratified intervention research could be conducted based on individual differences to enhance adaptability and intervention effectiveness.

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