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ARTICLE

Exploring the Associations of Physical Activity, Social Support, and Psychological Resilience in College Students: A Network Analysis

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ABSTRACT: Objectives: Psychological resilience is crucial to individual adaptation. Prior variable-based studies ignored node interactions. This study used network and regression approaches to analyze associations among physical activity, social support and college students' psychological resilience, screening core nodes and intervention targets. **Methods:** A total of 969 college students were investigated via cross-sectional survey. The International Physical Activity Questionnaire-Short Form (IPAQ-SF), the Social Support Scale (SSS), and the Connor-Davidson Resilience Scale (CD-RISC) were adopted to measure physical activity, social support and resilience. Network analysis, multiple linear regression, mediation and moderation models were applied for data processing. **Results:** Network analysis revealed that physical activity, social support, and psychological resilience formed clustered modular networks. "Individual Ability" was the central node with maximum strength (Strength = 1.302) and expected influence (EI = 1.261). "Perceived Social Support" served as the critical bridge between the physical activity and resilience modules, with the highest bridge expected influence (BEI ≈ 2.0). Regression analysis showed "Perceived Social Support" greatly predicted resilience ($\beta = 0.258$, $p < 0.001$), and partially mediated the relationship between high-intensity physical activity and resilience (indirect effect = 0.0047, 95% CI [0.0013, 0.0082]). Furthermore, gender significantly moderated the direct effect of social support on resilience (interaction B = 0.4717, $p = 0.014$), with a stronger positive association observed in females (B = 2.39) than in males (B = 1.92). **Conclusion:** Physical activity and social support tightly correlate with psychological resilience. Combined internal and external resource interventions and gender-differentiated resilience improvement strategies are suggested for college students.

KEYWORDS: Physical activity; social support; psychological resilience; network analysis; college students

1 Introduction

1.1 Background

The rising prevalence and multifaceted nature of mental health challenges among university students have made this issue a critical focus in global public health discourse. As higher education transitions from elitism to massification, students navigate an increasingly uncertain environment, facing persistent challenges from intensive academic demands, social adaptation pressures, and cross-cultural conflicts [1,2]. Psychological resilience—the capacity to "bounce back" and adapt positively to adversity, trauma, or

significant stressors—is widely recognized as a key protective factor for university students' mental health and social adjustment [3,4]. The university period represents a critical transitional phase from adolescence to early adulthood, during which students encounter multiple challenges, including heavy academic workloads, reconstruction of interpersonal networks, and career planning [5]. In this context, higher levels of resilience play an indispensable role in enabling students to effectively cope with these stressors, maintain psychological equilibrium, and prevent mental health problems.

1.2 Literature Review

To provide a theoretical basis for the combined use of network analysis and regression analysis, this section systematically reviews existing research on the relationships among physical activity, social support, and psychological resilience, and analyzes the strengths and limitations of different research perspectives.

1.2.1 The Association Mechanism between Physical Activity and Psychological Resilience

Previous research has extensively examined antecedents of individual resilience, among which physical activity and social support have emerged as two core predictors garnering significant attention [6]. In terms of physical activity, the World Health Organization (WHO) defines "physical activity" as: any bodily movement produced by skeletal muscles that requires energy expenditure [7]. A systematic review by Husain et al. (2024) [8] revealed that university students participating in sports and physical activities exhibited significantly higher resilience levels than their non-participating counterparts, with a dose-response relationship between activity frequency and resilience. This positive association was further corroborated by a meta-analysis conducted by Qiu et al. (2025) [9], which confirmed the relationship between physical activity and psychological resilience in young students.

Further research indicates that specific characteristics of physical activity produce differential effects on resilience enhancement. For instance, Kaçay et al. (2017) [10] found that physical education majors demonstrated significantly higher resilience than non-physical education students, with high-intensity training demonstrating stronger effects than moderate- or low-intensity activities. Mechanistically, physical activity enhances adaptive capacities through both neurobiological pathways (e.g., modulating neurotransmitter secretion, improving mood states, alleviating anxiety and depression) and psychosocial mechanisms (e.g., bolstering self-efficacy, providing opportunities for social interaction), in addition to promoting physical health [11,12].

However, existing studies have notable limitations. First, most research has treated physical exercise as a unidimensional variable, overlooking the differential effects of different intensities and types on psychological resilience. Second, previous studies have predominantly employed variable-centered approaches (e.g., traditional regression analysis), which treat variables as isolated predictors and fail to reveal the micro-interactive structures within the variable system, preventing the identification of core nodes and key pathways within the resilience system.

1.2.2 The Association Mechanism between Social Support and Psychological Resilience

Social support serves as a crucial external resource for coping with stress and plays a pivotal role in fostering resilience. Social support is defined as "the tangible and intangible resources acquired by individuals through relationships with others", and it is "one of the most effective resources for coping with stress" [13]. Encompassing perceived support, received support, and support utilization, social support significantly buffers the negative impact of life events by providing emotional comfort, informational guidance, and tangible assistance, thereby effectively enhancing individual resilience [6,14]. Research

on perceived social support in the literature has found that perceived social support is significantly positively related to psychological well-being and psychological resilience [15]. Narayanan and Weng Onn (2016) [16] further elucidated these mechanisms in their study of Malaysian first-year students, revealing that perceived social support and self-efficacy jointly predicted resilience development. Specifically, social support furnished a robust resource foundation for managing academic adaptation stress during the initial college transition by fulfilling individuals' needs for belonging and security.

While the positive association between social support and resilience is well-established, current research remains at the correlational level. Existing studies provide an important theoretical foundation, but the exploration of underlying mechanisms remains superficial. Specifically, these studies cannot identify which specific dimensions of social support serve as core vs. peripheral elements in the resilience network, nor can they examine dynamic interactions among different support sources.

1.2.3 The Integrated Association Mechanism among Physical Activity, Social Support, and Psychological Resilience

The Interplay between Physical Activity and Social Support: Physical activity is closely associated with social support among college students [17]. An active lifestyle not only benefits physical and mental health but also facilitates social interaction and the formation of support networks. Previous studies have indicated that physical activity increases social interaction opportunities [18]. For instance, team sports can enhance interpersonal communication skills, foster high-quality peer relationships, and help college students obtain greater social support. This suggests that physical activity may serve as a catalyst for building social resources, creating a positive feedback loop where physical engagement enhances social connectedness.

The Mediating Role of Social Support: Previous research has demonstrated that social support partially mediates the relationship between sports participation and psychological resilience [19]. Notably, team sports enhance resilience primarily through social support, whereas individual sports rely more on self-efficacy pathways. However, whether this mediating mechanism generalizes to broader physical activity contexts remains largely unexplored. Moreover, the systemic position of social support within the integrated physical activity-resilience network is unknown: Is it a central hub or peripheral connector? Does it serve as the primary bridge linking physical activity to resilience, or do alternative pathways exist? Traditional mediation analysis cannot answer these questions because it assumes linear, isolated relationships rather than interdependent network structures that capture the multidimensional nature of physical activity.

The Moderating Role of Gender: Research has shown that the association between social support and psychological resilience tends to be stronger in women [20]. This may be related to women's greater reliance on expressive and relational coping styles, which could strengthen their ties to emotional and social support [21–23]. However, it remains unclear whether and how gender moderates the overall system architecture. For instance, do male and female students differ in their network structures—such as in core elements or bridge connections? Is high-intensity physical activity more central in the network of male students compared to that of female students? To date, studies have primarily examined gender differences in isolated pathways, rather than from a systemic perspective that accounts for the multidimensional nature of physical activity.

1.3 Research Gaps

In summary, while previous literature has extensively explored the independent predictive effects of physical activity or social support on psychological resilience, the complex interaction mechanisms and internal system structures formed by these three factors have not been fully elucidated. Traditional regression analysis typically treats variables as isolated predictors, thereby failing to capture the interdependent network structure inherent in psychological and behavioral constructs. Consequently, key questions remain unanswered: What are the core and bridging elements within this system? Does social support serve as a critical bridge connecting physical activity to resilience within the network? Moreover, given established gender differences in patterns of physical activity, social support perception, and stress coping mechanisms, does the overall architecture of this system differ significantly between male and female students? Current research lacks an integrative framework that can simultaneously map this complex system and test specific theoretical pathways.

1.4 Study Objectives and Hypotheses

To address these gaps, this study adopts an innovative dual-method design integrating network analysis—a data-driven approach for visualizing complex variable systems and identifying core and bridging components [24]—with traditional multiple regression analysis. This framework aims to move beyond confirming established effects to uncovering the systemic structures and mechanisms underpinning these relationships. Specifically, this study seeks to: (1) visualize the complex network structure interlinking multiple dimensions of physical activity, social support, and psychological resilience; (2) identify core and bridging elements within this system, particularly whether social support serves as a critical bridge; (3) compare systemic network architectures between male and female students to investigate whether gender differences manifest at the structural level; and (4) integrate network analysis with regression analysis to validate whether network-identified bridge connections align with regression-identified mediation pathways. Based on these objectives, we hypothesize that:

Hypothesis 1: *In the network model encompassing physical activity, social support, and psychological resilience, significant correlations exist both within each domain and across different domains.*

Hypothesis 2: *Social support will mediate the positive relationship between high-intensity physical activity and psychological resilience.*

Hypothesis 3: *Gender will moderate the direct relationship between social support and psychological resilience.*

2 Method

2.1 Study Design

This cross-sectional study was conducted in June 2025 at Northwest Normal University in Lanzhou, Gansu Province, China. The target source population was undergraduate students aged 18–22 years at this university, with all observational participants selected from this group to ensure sample relevance and representativeness.

Following the STROBE guidelines for cross-sectional studies [25], a stratified cluster random sampling method was adopted. Stratification was performed by grade level, followed by random selection of classes within each stratum. Researchers collaborated with course instructors to briefly explain the study in class,

then distributed online questionnaire links via class WeChat groups. Anonymity and voluntary participation were emphasized to avoid response bias and ensure data authenticity.

Participant selection followed clear eligibility and exclusion criteria. Inclusion criteria: (1) 18–22-year-old undergraduates at the target university; (2) voluntary participation; (3) provided informed consent; (4) able to complete the questionnaire independently. Exclusion criteria for invalid questionnaires: (1) >20% missing items; (2) >80% regular/repetitive responses; (3) obvious logical inconsistencies.

All methods adhered to the Declaration of Helsinki and were approved by the Academic Ethics Committee of the Faculty of Psychology at Beijing Normal University (Approval No.: BNU202506160164). Informed consent was obtained from all individual participants included in the study. Participants were provided with comprehensive information about the study's purpose, procedures, and their rights, including the right to withdraw at any time without consequence.

A total of 1045 questionnaires were collected; 969 remained valid after screening (effective response rate: 92.73%), including 390 males (40.25%) and 579 females (59.75%). Detailed demographic information (by grade and gender) is presented in Table 1, with all analyses based on this cleaned dataset.

Table 1: Summary of data collection.

	Male (n = 390)	Female (n = 579)	Total/Proportion
Grade 1	184	350	534/55.1%
Grade 2	163	185	348/35.9%
Grade 3	30	38	68/7.0%
Grade 4	13	6	19/2.0%
Total/Proportion	390/40.2%	579/59.8%	969/100.0%

2.2 Measurement

2.2.1 Physical Activity

Participants' physical activity levels over the previous seven days were assessed using the International Physical Activity Questionnaire–Short Form (IPAQ-SF) [26]. The questionnaire consists of seven items covering four domains: vigorous-intensity physical activity, moderate-intensity physical activity, walking, and sedentary behavior, and is designed to capture the frequency, duration, and sitting time associated with daily physical activity [27]. To reduce self-report bias, standardized instructions were provided during data collection, and activity logs were used to supplement questionnaire responses and enhance data reliability [28]. In the present study, the IPAQ-SF demonstrated acceptable internal consistency, with a Cronbach's alpha coefficient of 0.75. The instrument has been widely validated across diverse populations and has shown good content validity for the comprehensive assessment of overall physical activity levels.

2.2.2 Social Support

Social support was assessed using the Social Support Scale (SSS). The 17-item instrument was developed by Ye et al. based on Xiao Shuiyuan's three-dimensional model of social support, encompassing subjective support, objective support, and support utilization [29]. The scale is designed to evaluate individuals' perceived availability, actual receipt, and active use of social support resources. In the present study, the SSS demonstrated good internal consistency, with a Cronbach's alpha coefficient of 0.78, indicating its suitability for assessing social support among the study participants.

2.2.3 Psychological Resilience

The Connor–Davidson Resilience Scale (CD-RISC) was employed to measure participants' psychological resilience. Originally developed by Connor and Davidson in 2003, the scale was translated and culturally adapted into Chinese by Xiao Nan and Zhang Jianxin in 2007 [30]. The CD-RISC consists of 25 items encompassing five dimensions: individual ability, sense of control, acceptance of change, tolerance of negative affect, and spiritual influences. Items are rated on a 5-point Likert scale ranging from 0 ("Never") to 4 ("Almost always"), with item 20 reverse scored. The total score is obtained by summing all item scores, yielding a possible range of 0–100, with higher scores indicating greater psychological resilience. Previous studies have demonstrated excellent psychometric properties of the CD-RISC, with an internal consistency coefficient of 0.90 and a split-half reliability coefficient of 0.87, supporting its reliability and validity in resilience assessment.

2.3 Data Analysis

In this study, data analyses were performed using a combination of network analysis and regression analysis to explore the complex relationships among the study variables. All network analyses were conducted with R 4.5.1 (R Foundation for Statistical Computing, Vienna, Austria). The main R packages employed were as follows: qgraph (version 1.9.8) for network construction and visualization [31]; bootnet (version 1.6) for network stability evaluation; NetworkComparisonTest (version 2.2.1) for network structure comparison; and ggplot2 (version 3.5.0) for graph plotting [22]. Descriptive statistics were computed using IBM SPSS Statistics (Version 29.0, IBM Corp., Armonk, NY, USA). Separate mediation and moderation analyses were conducted using the PROCESS macro (Version 4.1; Hayes, 2022) for SPSS. Specifically, Model 4 was used for mediation analysis, while Model 1 was applied for moderation analysis.

2.3.1 Overview of the Analytical Procedure

As shown in Fig. 1, the analytical procedure was structured in two sequential phases. Phase I (Network Analysis) employed a Gaussian Graphical Model (GGM) with LASSO regularization to estimate the network structure of the 12 nodes across the three conceptual modules. Subsequently, node centrality and bridge centrality indices were calculated, followed by stability and accuracy tests. A Network Comparison Test (NCT) was then conducted to examine sex differences in the overall network structure. Phase II (Regression and Path Analysis) built upon the network findings to test specific mechanisms. First, multiple regression analyses were performed for the total sample and for each sex separately. Second, a mediation model was tested to examine whether social support mediated the relationship between high-intensity physical activity and psychological resilience. Third, a moderation model was tested to determine whether sex moderated the direct effect of social support on resilience. The detailed analytical procedure is illustrated in Fig. 1.

2.3.2 Phase I: Network Analysis (System Structure)

Initially, all continuous variables were standardized to Z-scores. A Gaussian Graphical Model (GGM) [32] was estimated to construct a partial correlation network comprising 12 nodes, categorized into three conceptual modules: physical activity (4 nodes), social support (3 nodes), and psychological resilience (5 nodes). To obtain a sparse and interpretable network structure, graphical LASSO (glasso) regularization was applied, with model selection guided by the Extended Bayesian Information Criterion (EBIC). The hyperparameter γ was set to 0.5 to balance sensitivity and specificity. Following network estimation, node centrality indices (strength, betweenness, closeness, and expected influence) were calculated to identify the most influential nodes within the system. Furthermore, bridge centrality indices (bridge strength and

bridge expected influence) were computed to identify nodes acting as critical connectors between different modules (e.g., linking physical activity and resilience). The robustness of the network was assessed using non-parametric bootstrapping (5000 resamples) to estimate confidence intervals for edge weights [33]. The correlation stability coefficient (CS-coefficient) was calculated via the case-dropping bootstrap method to evaluate the stability of centrality indices. Finally, a Network Comparison Test (NCT) was conducted to examine significant differences in overall network structure or specific edge weights between male and female subgroups [34].

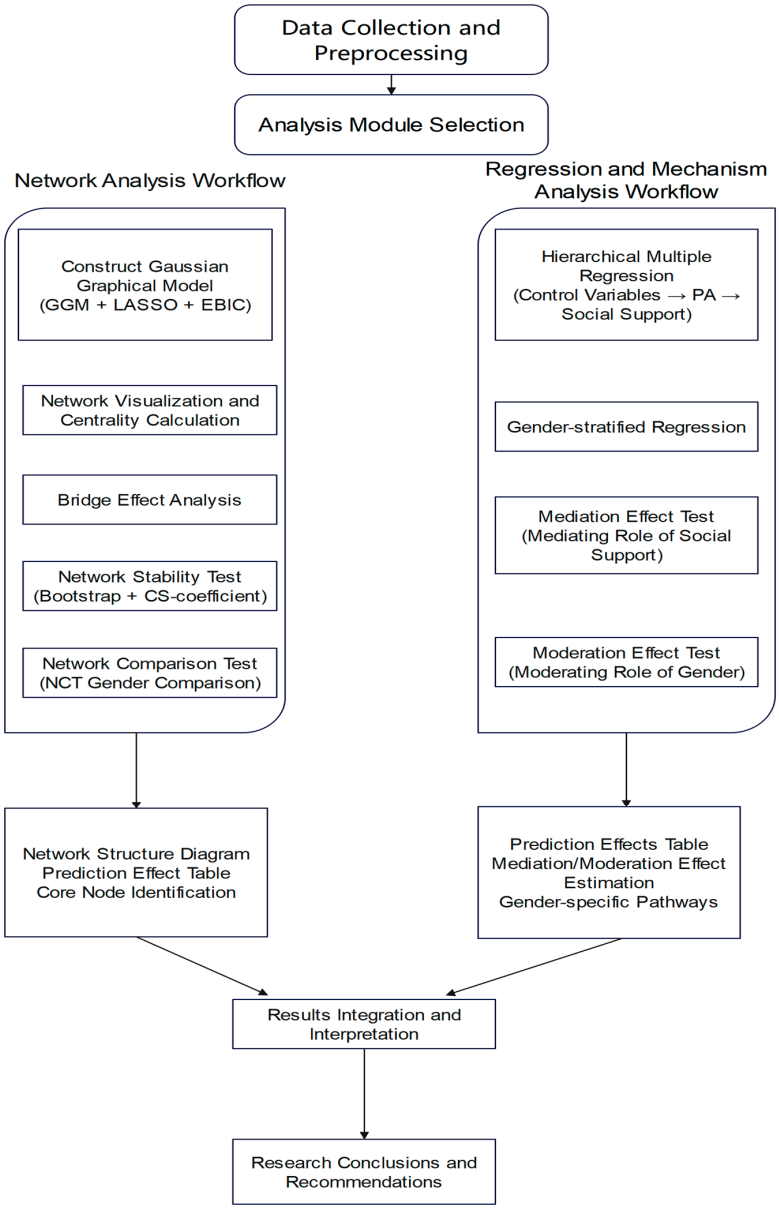

Figure 1: Flowchart of network analysis and regression mechanism analysis. Note: GGM: Gaussian Graphical Model; LASSO: Least Absolute Shrinkage and Selection Operator; EBIC: Extended Bayesian Information Criterion; CS: Correlation Stability Coefficient; NCT: Network Comparison Test; PA: Physical Activity.

2.3.3 Phase II: Regression and Path Analysis (Mechanism Testing)

Building upon the findings from the network analysis, we proceeded to test directional hypotheses regarding mediation and moderation. First, hierarchical multiple regression analysis was conducted with the total psychological resilience score as the dependent variable. Demographic variables, physical activity indicators, and social support dimensions were entered into the model sequentially to examine their incremental predictive power (ΔR^2). Gender-stratified regression analyses were performed to identify distinct predictive patterns [35]. Second, guided by the network structure, we tested a mediation model using PROCESS Model 4 (bias-corrected bootstrapping with 5000 resamples) [36]. Vigorous-intensity physical activity was specified as the independent variable, psychological resilience as the dependent variable, and social support as the mediator. Third, to examine whether the effect of social support on psychological resilience varies by gender, a moderation analysis was conducted using PROCESS Model 1. The interaction term (social support × gender) was examined to interpret significant interactions. All statistical tests were two-tailed, with statistical significance set at $p < 0.05$.

3 Results

3.1 Analysis of Variable Associations

The correlation analysis revealed key patterns among the variables (see Fig. 2). Regarding cross-dimensional associations, the strongest positive relationship was observed between social support and psychological resilience, with correlations among their respective sub-dimensions (e.g., Perceived Support, Acceptance of Change) ranging from a moderate-to-strong 0.38 to 0.58. In contrast, associations involving physical activity were weaker; weekly walking time showed weak positive correlations with all sub-dimensions of social support and psychological resilience (r = 0.02–0.17), while high-intensity physical activity was only slightly linked to Individual Ability and Endurance of Negative Affect. Within the dimensions, the social support module exhibited the strongest internal connections, with Support Utilization being highly correlated with Objective Support (r = 0.86) and Perceived Social Support with Support Utilization (r = 0.85). The psychological resilience module followed, with sub-dimensions such as Sense of Control and Individual Ability (r = 0.86) as well as Individual Ability and Tolerance of Negative Affect (r = 0.84) showing strong positive correlations. Finally, the physical activity module had the weakest internal associations, where sedentary behavior was only weakly negatively correlated with high- and moderate-intensity physical activity (r = −0.07 and r = −0.02, respectively).

3.2 Network Analysis

As illustrated in Fig. 3, we constructed a “Physical Activity-Social Support-Resilience” network comprising 12 nodes with up to 66 potential edges. The network density was 59.10%, consisting of 39 non-zero edges with an average weight of 0.11. The analysis revealed that within the domain of social support, the strongest correlation was observed between “objective support” and “utilization of support”; regarding physical activity, the strongest correlation existed between “high-intensity physical activity” and “moderate-intensity physical activity”. In terms of resilience, the most robust association was identified between “sense of control” and “individual ability”. Furthermore, the core cross-community associations included: perceived social support with “acceptance of change” and “individual ability”, and objective support with “acceptance of change”.

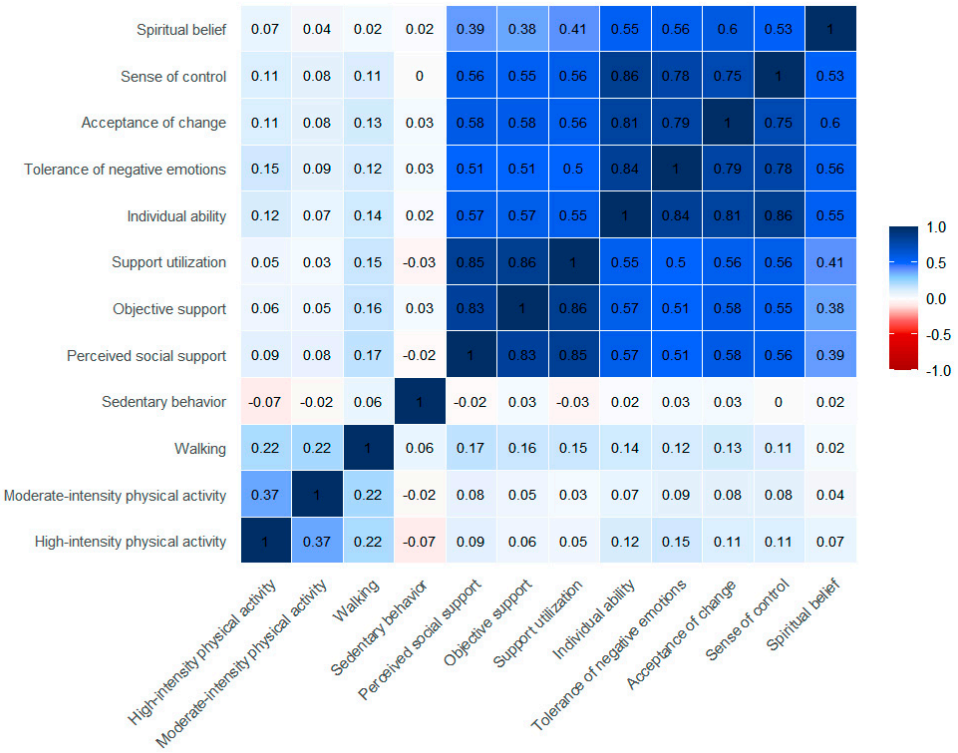

Figure 2: Partial correlation coefficients between nodes.

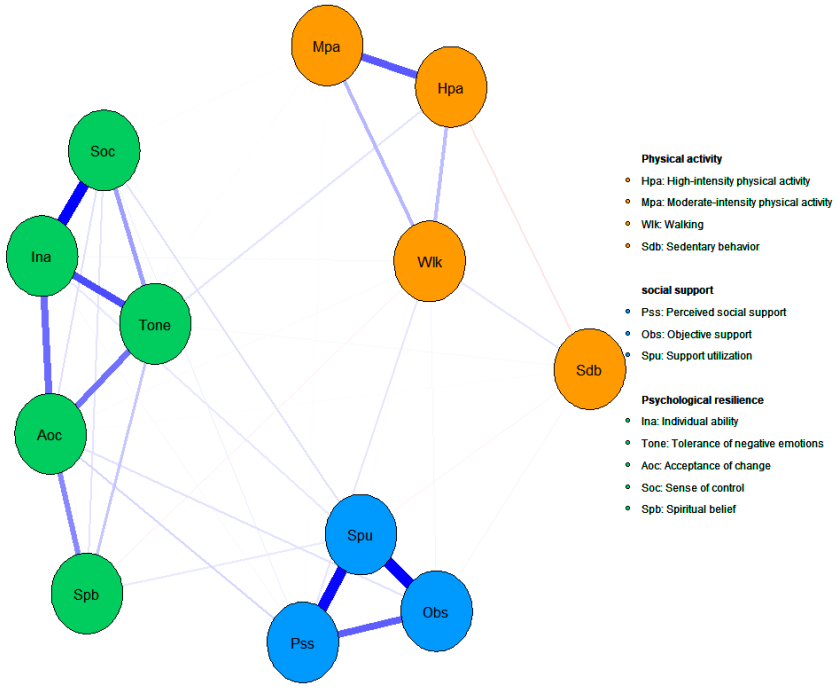

Figure 3: The network of physical activity, social support, and psychological resilience. Note: Hpa: High-intensity physical activity. Mpa: Moderate-intensity physical activity. Wlk: Walking. Sdb: Sedentary behavior. Pss: Perceived social support. Obs: Objective support. Spu: Support utilization. Ina: Individual ability. Tone: Tolerance of negative emotions. Aoc: Acceptance of change. Soc: Sense of control. Spb: Spiritual belief.

3.2.1 Overall Network Centrality Analysis

In this study, Z-scores (standard scores) were utilized to standardize the overall network centrality indices pertaining to physical activity, social support, and psychological resilience. The results are illustrated in Fig. 4, with detailed values provided in Table S1 (Supplementary Materials).

To identify the most influential nodes within the network, we calculated centrality indices including strength, expected influence, betweenness, and closeness. The results indicate that "individual ability" exhibited the highest strength (1.302) and expected influence (1.261), signifying robust connectivity and a substantial positive influence on the entire network. This suggests its potential role as a core node in maintaining the overall network system. In contrast, "acceptance of change" and "high-intensity physical activity" demonstrated relatively high betweenness (1.387 and 1.243, respectively). It is worth noting that while betweenness can reflect a node's role in connecting other nodes, this index primarily characterizes a node's position within the overall network structure, rather than its specific function in bridging distinct conceptual modules. Furthermore, "sedentary behavior" had the lowest strength (−1.867) and closeness (−2.434), indicating weak connectivity and greater distance from other nodes, thereby occupying a more peripheral position in the network.

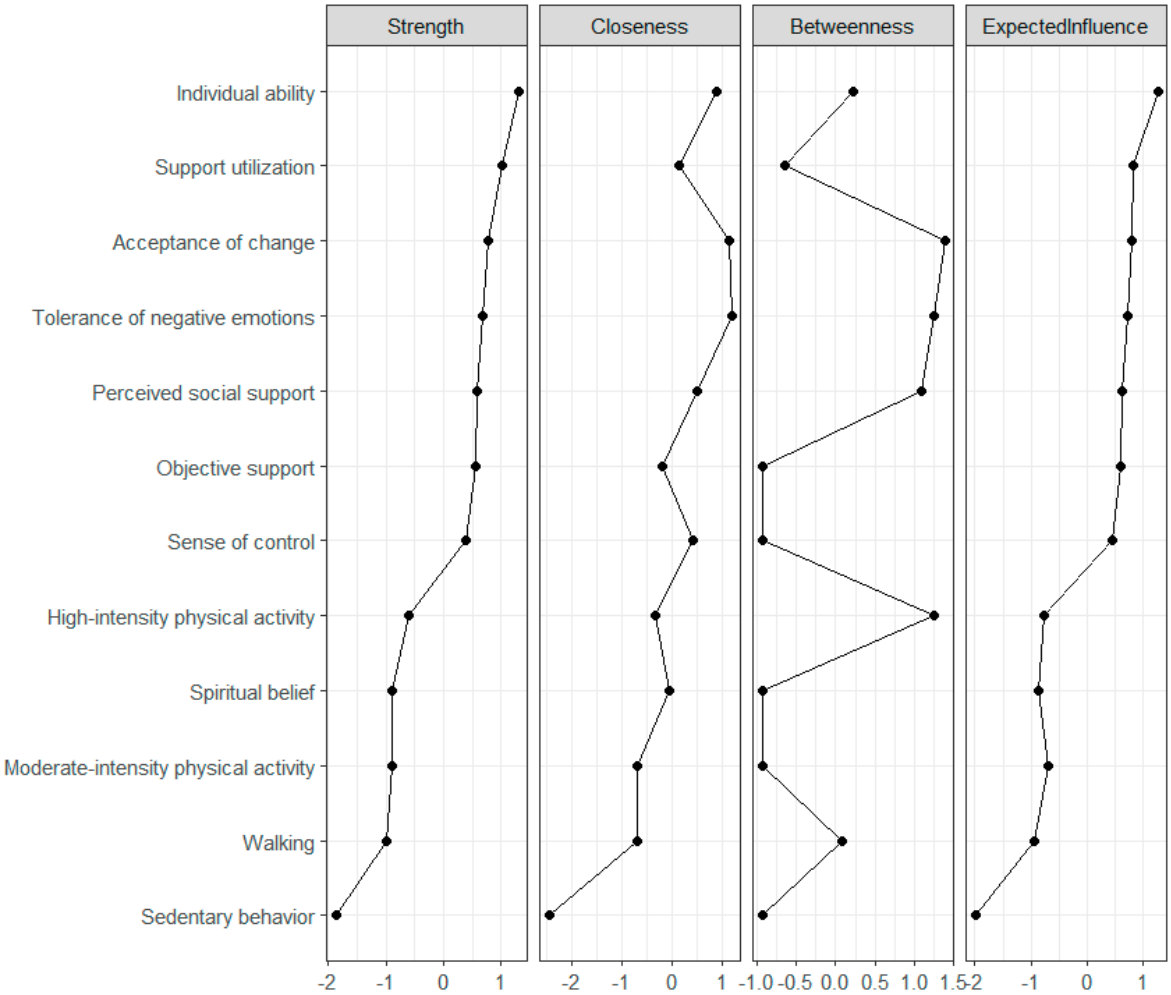

Figure 4: Comparison chart of strength, closeness, betweenness and expected influence of different nodes.

3.2.2 Bridge Centrality Analysis: Identifying Cross-Module Connectors

The Bridge Expected Influence (BEI) analysis (see Fig. 5) was used to quantify each node's cross-community influence across the psychological resilience, social support, and physical activity communities (higher values indicate greater bridging influence). Perceived social support showed the highest BEI (≈2). Relatively higher BEI values were also observed for Sense of control, Objective support, and Acceptance of change. Walking, Tolerance of negative emotions, Individual ability, and Support utilization showed intermediate BEI values. Lower BEI values were observed for Spiritual belief, Moderate-intensity physical activity, and High-intensity physical activity. Sedentary behavior had the lowest BEI (≈−1).

Bridge strength (BS) results (see Fig. 6) indicated marked between-node differences. Perceived social support had the highest bridge strength (BS = 0.180), followed by Acceptance of change (BS = 0.150), and Support utilization and Objective support (both BS = 0.140). Walking (BS = 0.120) and Sense of control (BS = 0.100) were intermediate. Lower values were observed for Spiritual belief (BS = 0.077), Individual ability (BS = 0.070), and Tolerance of negative emotions (BS = 0.064). Physical activity indicators were generally smaller, including High-intensity physical activity (BS = 0.061) and Sedentary behavior (BS = 0.057), with Moderate-intensity physical activity lowest (BS = 0.012).

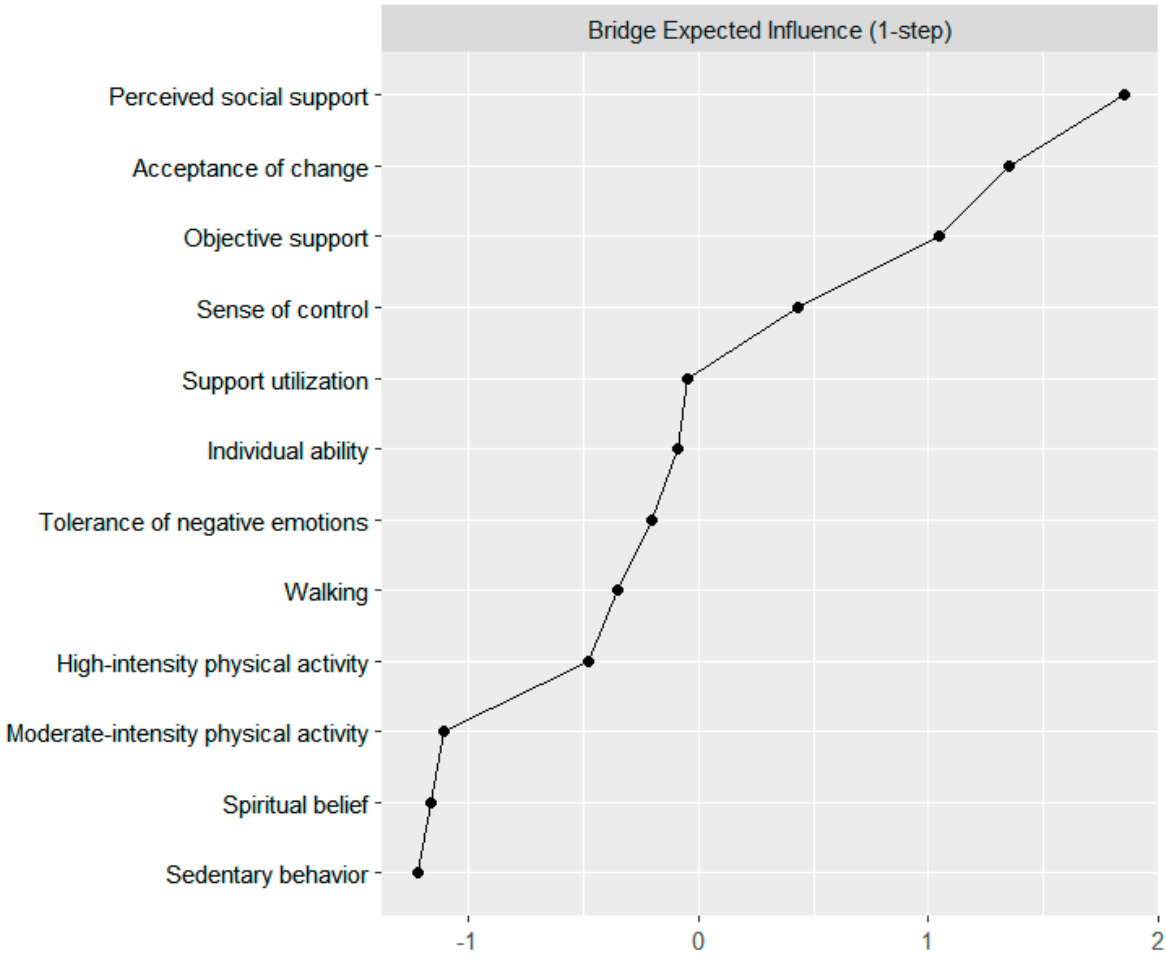

Figure 5: The expected impacts of bridges at each node.

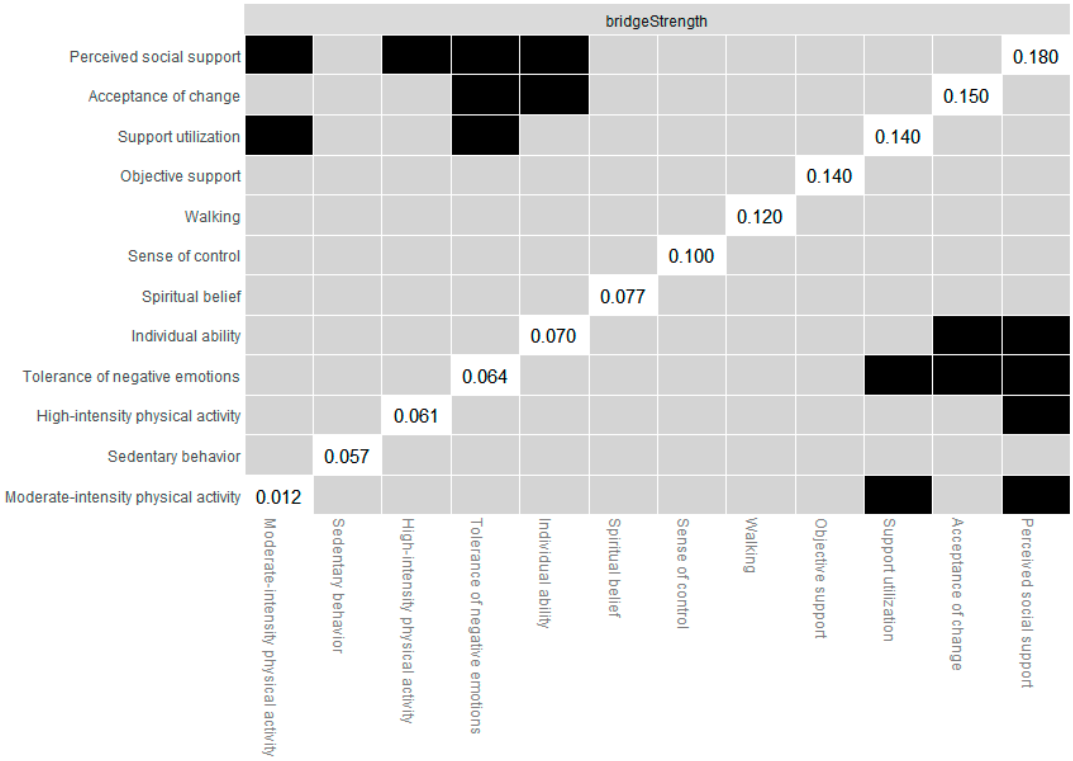

Figure 6: Bridge strength matrix.

3.2.3 Network Stability and Accuracy

We conducted a case-dropping bootstrap procedure to evaluate the correlation stability (CS) of network estimates. As shown in Fig. 7, we assessed the average correlation between subsample and original sample estimates across different case retention levels.

Strength, expected influence, and edge weights demonstrated excellent stability: the maximum proportion of cases that could be dropped while maintaining a correlation ≥0.70 in over 95% of bootstrap samples reached 0.75 (the highest level tested). Edge weights were the most stable metric, with average correlations approaching 1.0 across nearly all sampling levels, indicating negligible fluctuation and exceptional reproducibility.

In contrast, bridge strength showed a gradual decline in correlation (from ~0.95 to ~0.68), indicating lower stability under subsampling. These findings align with the overall centrality stability pattern in supplementary analysis (see Fig. S1). Bootstrap difference tests also revealed that most comparisons between expected influence and node strength were statistically significant (see Fig. S2, Supplementary Materials).

3.2.4 Network Comparison

As illustrated in the network plots (see Fig. 8), both the female and male groups exhibit three distinct clusters representing overarching health domains: Physical Activity, Social Support, and Psychological Resilience. Visually, the intensity of intra-domain edges is generally stronger than that of inter-domain edges in both networks, indicating robust internal consistency within these dimensions. This global structural similarity suggests that males and females share a consistent fundamental network composition.

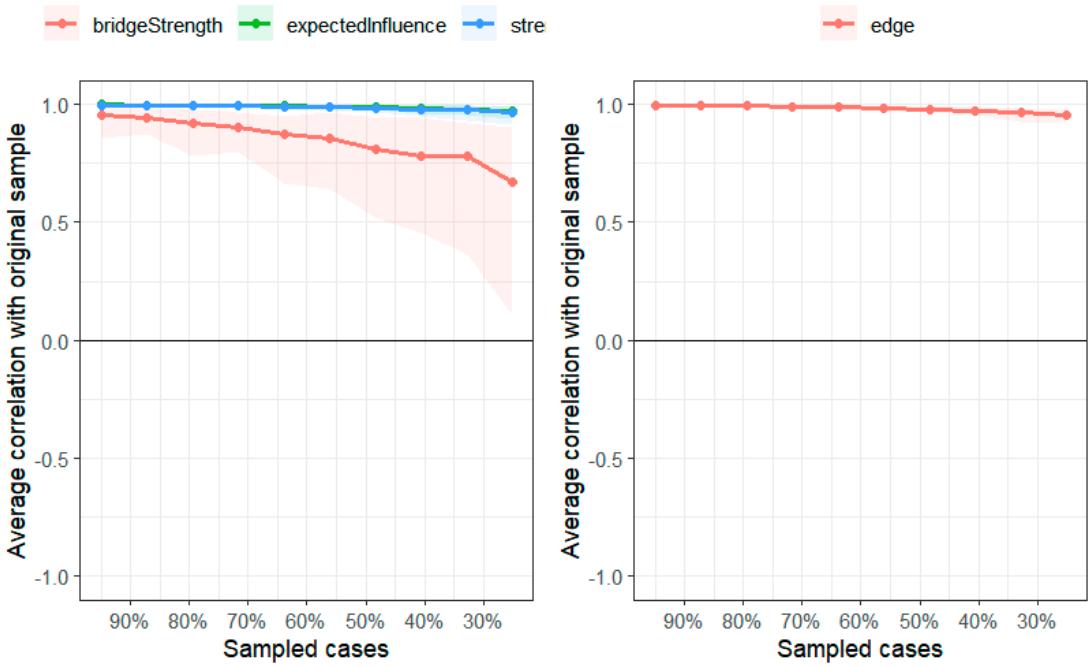

Figure 7: Stability of edge weights and centrality indices.

However, distinct gender-specific patterns emerge when evaluating overall node centrality (Strength and Expected Influence) based on Z-score indices (see Table S2). In the female network, "Individual ability" (Ina) functions as the most central component, exhibiting the highest Strength (1.682) and Expected Influence (1.585). Conversely, the male network is characterized by different core nodes; "Support utilization" (Spu) shows the highest Strength (1.299), while "Acceptance of change" (Aoc) demonstrates the highest Expected Influence (0.923). Notably, "Sedentary behavior" (Sdb) exhibits low overall centrality indices across both groups (Z-scores < 0), indicating a peripheral role within the global health-behavior networks.

To rigorously evaluate inter-domain connectivity, we analyzed Bridge Expected Influence (1-step, BEI) (see Table S3; Figs. S3 and S4). For the female group, Objective support (Obs, BEI = 0.230) was the node with the highest bridge expected influence, followed closely by Perceived social support (Pss, BEI = 0.1782) (Fig. S3). This indicates that actual social support resources and their subjective perception are the primary bridges linking the social support domain to psychological resilience and physical activity. In contrast, for the male group, Perceived social support (Pss, BEI = 0.2343) was the top bridge node, with Acceptance of change (Aoc, BEI = 0.1729) and Objective support (Obs, BEI = 0.2141) ranking as the second and third highest, respectively (Fig. S4). This suggests that for males, perceived social support acts as the critical conduit connecting disparate health domains, while psychological adaptability to change and objective support resources also play strong bridging roles.

To validate the statistical reliability of these findings, we further computed Centrality Stability Coefficients (CS) (see Table S4): Basic centrality metrics (Strength/Expected Influence) exhibited extremely high stability across both genders (CS = 0.7506 for males, CS = 0.7496 for females, both well above the threshold for high stability of 0.5), confirming that the centrality of core nodes is robust to sampling variation. Bridge Expected Influence also met acceptable stability thresholds (CS = 0.4396 for males, CS = 0.3610 for females, both > 0.25), with male bridge stability being significantly higher than female. This indicates that the inter-domain bridging effects of key male nodes are more consistent, while female bridge results are relatively more sensitive to sample fluctuations.

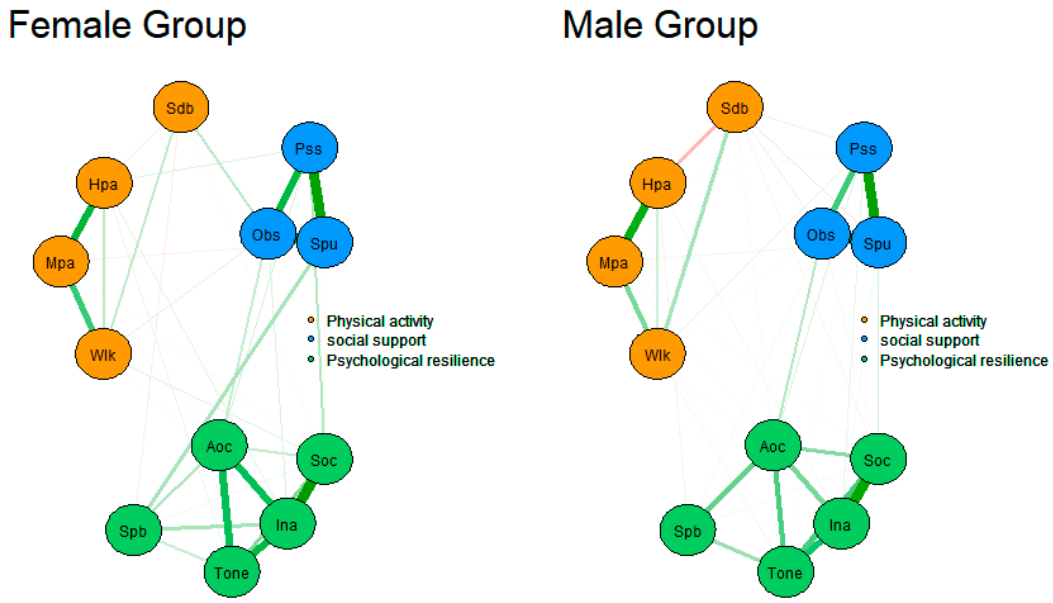

Figure 8: Comparison of indicators of physical activity, social support, and psychological resilience between male and female groups. Note: Hpa: High-intensity physical activity. Mpa: Moderate-intensity physical activity. Wlk: Walking. Sdb: Sedentary behavior. Pss: Perceived social support. Obs: Objective support. Spu: Support utilization. Ina: Individual ability. Tone: Tolerance of negative emotions. Aoc: Acceptance of change. Soc: Sense of control. Spb: Spiritual belief.

3.3 Multiple Linear Regression Analysis

The optimized regression model explained a substantial proportion of variance in psychological resilience (Table 2). For the total sample, the adjusted R^2 was 0.400 ($F = 162.027$, $p < 0.001$), representing a moderate-to-large effect size. Gender-stratified analyses revealed a better model fit for females (Adjusted $R^2 = 0.435$) compared to males (Adjusted $R^2 = 0.350$).

In the total sample, all four predictors contributed uniquely. Perceived social support was the strongest predictor ($B = 0.953$, $\beta = 0.258$, $p < 0.001$), followed by objective support ($B = 0.739$, $\beta = 0.241$, $p < 0.001$). High-intensity physical activity ($B = 0.007$, $\beta = 0.084$, $p < 0.001$) and support utilization ($B = 0.470$, $\beta = 0.157$, $p < 0.001$) also showed significant positive associations with psychological resilience.

Distinct gender-specific patterns emerged. For males, perceived ($B = 1.099$, $\beta = 0.312$, $p < 0.001$) and objective support ($B = 0.850$, $\beta = 0.287$, $p < 0.001$) were the primary drivers, with high-intensity physical activity also significant ($B = 0.008$, $\beta = 0.111$, $p < 0.001$); support utilization was not retained in the model. Conversely, for females, support utilization was the most salient predictor ($B = 0.808$, $\beta = 0.264$, $p < 0.001$), followed by perceived ($B = 0.893$, $\beta = 0.233$, $p < 0.001$) and objective support ($B = 0.613$, $\beta = 0.195$, $p < 0.001$); high-intensity physical activity was excluded.

These findings indicate that while social support is universally crucial, pathways to psychological resilience differ by gender: men benefit more from high-intensity activity and perceived support, whereas women's resilience is more strongly linked to the active utilization of support resources. Consequently, gender-tailored interventions may enhance the effectiveness of programs aimed at improving adaptive functioning.

Table 2: Predictors of psychological resilience: Results from the optimized regression model for the total sample, males, and females.

Model		Adjusted R Square	Std. Error of the Estimate	F	*P*	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
						B	SE	Beta		
Total Sample	Constant	0.400	10.651	162.027	<0.001	22.475	1.788	-	12.571	<0.001
	Perceived social support					0.953	0.189	0.258	5.045	<0.001
	Objective support					0.739	0.159	0.241	4.634	<0.001
	High-intensity physical activity					0.007	0.002	0.084	3.368	<0.001
	Support utilization					0.470	0.169	0.157	2.779	<0.001
Male	Constant	0.350	11.023	70.619	<0.001	27.078	2.798	-	9.677	<0.001
	Perceived social support					1.099	0.244	0.312	4.509	<0.001
	Objective support					0.850	0.204	0.287	4.169	<0.001
	High-intensity physical activity					0.008	0.003	0.111	2.678	<0.001
Female	(Constant)	0.435	10.374	149.384	<0.001	19.639	2.325	-	8.447	<0.001
	Support utilization					0.808	0.245	0.264	3.301	<0.001
	Perceived social support					0.893	0.260	0.233	3.433	<0.001
	Objective support					0.613	0.223	0.195	2.754	<0.001

Note: F: F-statistic; *P*: Significance value; B: Unstandardized Coefficient; SE: Standard Error; t: *t*-test; Sig.: Significance.

3.4 Mediation and Moderation Analyses

To investigate the underlying mechanisms linking physical activity, social support, and psychological resilience, a mediation analysis was conducted using Model 4 of the PROCESS macro (see Table 3). High-intensity physical activity (HIPA) was set as the independent variable, psychosocial support (PSS) as the mediator, and psychological resilience (PR) as the dependent variable. The results indicated that high-intensity physical activity significantly and positively predicted social support (B = 0.0022, $p < 0.004$), and social support significantly and positively predicted psychological resilience (B = 2.1885, $p < 0.001$). When controlling for the mediator, the direct effect of high-intensity physical activity on psychological resilience remained significant (B = 0.0065, $p < 0.003$). Furthermore, the 95% bias-corrected bootstrap confidence interval for the indirect effect was [0.0013, 0.0082], which did not include zero, indicating that social support plays a partial mediating role between high-intensity physical activity and psychological resilience.

To further examine the moderating effect of gender on the relationship between social support and psychological resilience, a moderation analysis was performed using Model 1 (see Table 4). The results showed a significant interaction between social support and gender (B = 0.4717, $p < 0.014$). Simple slope analyses revealed that for males, social support significantly and positively predicted psychological resilience (B = 1.9233, $p < 0.001$). In contrast, this predictive effect was significantly stronger for females (B = 2.3949, $p < 0.001$). This indicates that there is a significant gender difference in the promotive effect of social support on psychological resilience, with the psychological resilience of the female group being more responsive to social support resources.

Table 3: Indirect effect of physical activity on psychological resilience via psychosocial support.

Path	Coefficient (B)	*p*-Value	95% CI
High-intensity PA (HIPA) → Psychosocial Support (PSS)	0.0022	0.004	[0.0007, 0.0036]
Psychosocial Support (PSS) → Psychological Resilience (PR)	2.1885	<0.001	[2.0020, 2.3751]
Direct Effect (HIPA → PR)	0.0065	0.003	[0.0022, 0.0109]
Indirect Effect (via PSS)	0.0047	-	[0.0013, 0.0082]

Table 4: Moderating effect of gender on the relationship between psychosocial support and psychological resilience.

Effect Type	Coefficient (B)	*p*-Value	95% CI
Interaction (PSS × Gender)	0.4717	0.014	[0.0967, 0.8466]
Male (Simple Slope)	1.9233	<0.001	[1.6411, 2.2054]
Female (Simple Slope)	2.3949	<0.001	[2.1462, 2.6436]

Note: SS: Social support.

4 Discussion

This study aimed to elucidate the complex associations among physical activity, social support, and resilience in university students. By integrating network analysis, regression models, and mediation/moderation tests, the findings revealed robust structural links between psychosocial factors and physical activity behaviors, while also highlighting potential intervention targets within the psychological system.

Regarding the hypotheses proposed in the introduction, the verification results are as follows: First, Hypothesis 1 was fully supported. The network analysis confirmed that physical activity, social support,

and psychological resilience form an interconnected network system characterized by significant modular clustering, with notable correlations both within and across these domains (see Fig. 3). Second, Hypothesis 2 was confirmed. The mediation analysis revealed that social support partially mediates the relationship between high-intensity physical activity and psychological resilience, indicating an indirect pathway through which vigorous exercise contributes to resilience (see Table 3). Third, Hypothesis 3 was supported. The moderation analysis demonstrated that gender significantly moderates the direct effect of social support on psychological resilience, with the positive association being significantly stronger in females than in males. This confirms that gender functions as a moderator in the relationship between social support and resilience, highlighting a critical gender-specific pattern (see Table 4).

First, our results demonstrated a strong positive association between social support and resilience, which was highly consistent with the network structure. In the correlational analysis, the strongest associations were observed between the dimensions of social support and resilience. The network analysis further showed tightly connected clusters within both the resilience module and the social support module. Furthermore, the traditional psychiatric view that social support is a protective factor for mental health was still supported in our study after controlling for the influence of all domains [37]. From a network perspective, the results elucidate the distinct roles played by different nodes. Firstly, when examining overall network centrality (see Fig. 4), "individual ability" emerged as the most central node, exhibiting the highest strength and expected influence. This suggests that, within this interconnected system, an individual's perceived competence and self-efficacy (i.e., individual ability) may be a key internal psychological resource for maintaining the overall integrity and function of the resilience network. Secondly, when focusing on cross-modular connectivity (see Figs. 5 and 6), "perceived social support" demonstrated the highest bridge expected influence and bridge strength. This indicates that while it belongs to the social support module, it serves as the primary gateway or crucial pathway for connecting external support resources to the internal psychological resilience system. This dual finding highlights that interventions could target "individual ability" to strengthen the whole system, while leveraging "perceived social support" as a strategic leverage point to facilitate beneficial cross-domain effects.

This pattern aligns well with prior evidence. Across diverse populations, perceived social support has been consistently linked to higher resilience and jointly buffers stress and negative emotions. For example, studies among COVID-19 patients found that greater perceived social support and stronger resilience were associated with lower perceived stress and depressive symptoms, and that their effects on mental health outcomes may operate through sequential mediation pathways, supporting a relatively stable "support–resilience–stress/depression" mechanism [38]. Similarly, research in postgraduate students showed that perceived social support not only directly predicted resilience but also indirectly enhanced resilience through reduced stress and increased general self-efficacy, indicating that social support may strengthen internal resilience by promoting competence-related beliefs and resource mobilization [39]. In addition, the pivotal role of individual ability in psychological resilience has been consistently emphasized across the literature. Schultze-Lutter et al. (2016) explicitly conceptualize "perceived competence and empowerment" as core intrapersonal assets of resilience, distinguishing them from environmental resources [40]. Similarly, Brooks et al. (2020), in their systematic review of disaster-exposed personnel, identified "individual ability" as one of three primary protective factors [41]. Therefore, the 'individual ability (central node)–perceived social support (bridge node)' pattern identified in this study not only corroborates existing mechanistic models but also extends them from a network perspective. These findings further suggest that interventions targeting individual ability and the perception/utilization of social support may be more effective in enhancing psychological resilience and its stability than merely increasing objective support.

Second, physical activity exhibited a distinct pattern of associations with resilience and social support. Although the network analysis indicated that the connections between physical activity and other variables were generally weaker than the internal links between social support and resilience, the regression findings showed that high-intensity physical activity (HIPA) significantly and positively predicted resilience. This suggests that the role of physical activity in the resilience system may be more evident at higher intensity levels, where cumulative psychological and physiological gains are more likely to occur. This finding is consistent with prior research demonstrating that higher levels of physical activity—particularly vigorous or sustained engagement—are associated with greater resilience and more favorable mental health outcomes [42,43], and that resilience often serves as a key mechanism linking physical activity to psychological well-being.

More importantly, our mediation analysis confirmed that social support partially mediated the relationship between HIPA and resilience. This indicates that vigorous exercise may promote resilience not only through direct intrapersonal processes (e.g., improved emotion regulation and self-efficacy), but also indirectly by fostering interpersonal engagement and social connectedness, thereby enhancing perceived and utilized social support [44–46]. Supporting this explanation, prior studies have reported significant pathways among physical activity, social support, and resilience, and have shown that both social support and resilience can function as mediators in the association between physical activity and mental health or subjective well-being [47,48]. Furthermore, evidence from systematic reviews suggests that sport participation—especially team-based or socially embedded forms—can generate stronger social benefits and support networks, which may translate into more sustainable psychological adaptation. Taken together, the present findings highlight the dual value of physical activity, particularly high-intensity or socially contextualized exercise, in simultaneously building social support and strengthening resilience, thereby representing a promising and feasible intervention avenue for improving university students' psychological adjustment and mental health.

Third, this study elucidates significant gender differences, which are critical for understanding psychosomatic interaction mechanisms. Multiple linear regression, moderation, and network comparison analyses collectively demonstrate distinct adaptive patterns between males and females. Specifically, regression analyses reveal that psychological resilience in males is primarily predicted by perceived social support, objective support, and high-intensity physical activity. In contrast, high-intensity physical activity is excluded from the female predictive model, where resilience relies most heavily on the active utilization of social support. Moderation analysis further confirms that females are significantly more sensitive to the conversion of social support resources into resilience. Furthermore, Network analyses further clarify these gender-specific structural differences. Sedentary behavior occupies a consistently peripheral position in both gender-specific networks. For females, global centrality (Strength and Expected Influence) identifies individual ability as the most central node within the psychological health network, while bridge centrality (Bridge Expected Influence) highlights objective support and perceived social support as the key bridges connecting different health domains. For males, global centrality characterizes the network with support utilization and acceptance of change as the most central nodes, whereas bridge centrality identifies perceived social support as the primary bridge across domains, followed by acceptance of change and objective support. These findings align with previous research. For instance, Siddiqui et al. (2019) [49] noted a stronger correlation between perceived social support and resilience in females, while physical activity participation was more closely linked to resilience in males. Similarly, Saddique et al. (2021) [6] observed that male college students rely more on the direct effects of physical activity, whereas female students depend more on the mediating effects of social support.

Based on these findings, the present study offers significant practical implications. Educators and counselors could consider adopting a comprehensive perspective when designing mental health promotion programs, with potential integration of gender-tailored strategies. Specifically, for males, promoting physical exercise—particularly high-intensity activities that may foster a sense of challenge and achievement—alongside interventions aimed at enhancing psychological adaptability to change, might yield positive outcomes. For females, interventions that focus on cultivating intrinsic individual ability and constructing robust social support systems, including explicit training in practical support utilization skills, may help facilitate the efficient conversion of available social resources into psychological resilience.

However, this study has certain limitations. First, the cross-sectional design restricts the ability to establish definitive causal relationships between variables. Second, reliance on self-reported data may introduce recall and response biases. Third, the sample was limited to a single university in Lanzhou, restricting regional representativeness. Future research should employ longitudinal designs to verify causal chains, expand sample diversity, and design targeted intervention experiments based on network analysis findings to validate specific pathways for enhancing resilience. In addition, given that the sample was limited to a single university in Lanzhou, future studies should recruit more diverse and representative samples across different regions and cultural contexts to enhance the generalizability of the findings.

5 Conclusion

This study combined network analysis and regression analysis to elucidate the interaction mechanisms among physical activity, social support, and psychological resilience in college students, revealing distinct gender-specific patterns. Regarding network structure, female networks are primarily characterized by the high **global centrality** of “individual ability”, with “objective support” and “perceived support” serving as key nodes in **bridge centrality**. Conversely, male networks feature “support utilization” as a prominent node in **global centrality**, while “perceived support” and “acceptance of change” function as the primary nodes in **bridge centrality**. Furthermore, regression models indicate that high-intensity physical activity is positively associated with resilience both directly and indirectly via social support. Specifically, resilience in males is more strongly predicted by high-intensity activity and perceived support, whereas resilience in females appears more closely linked to active support utilization. Given the cross-sectional nature of this study, these findings tentatively suggest that future mental health interventions may benefit from gender-tailored approaches: potentially emphasizing high-intensity physical challenges and adaptability training for males, while focusing on cultivating intrinsic capabilities and practical support-utilization skills for females.

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