



OPEN Chain mediated effects of stress perception and loneliness on the relationship between physical exercise and internet addiction among chemistry majors in college

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To explore the mechanism by which physical exercise influences internet addiction among chemistry majors and to analyze the chain mediating effects of perceived stress and loneliness. A questionnaire survey was conducted on 900 Chinese chemistry majors using the physical exercise rating scale, internet addiction scale, stress perception scale, and loneliness scale. The direct effect of physical exercise on internet addiction among chemistry majors was -0.171 . The effect sizes for perceived stress and loneliness, mediating between physical exercise and internet addiction, were -0.010 and -0.001 , respectively. The chain mediating effect of perceived stress and loneliness was significant, with an effect size of -0.002 . (1) Physical exercise significantly negatively predicted perceived stress, loneliness, and internet addiction; (2) Both the direct and indirect effects of physical exercise on internet addiction among chemistry majors were significant. (3) Physical exercise significantly predicted internet addiction through the independent mediating effects of perceived stress and loneliness, and also significantly predicted internet addiction through the chain mediating effects of perceived stress and loneliness.

Keywords Physical exercise, Internet addiction, Stress perception, Loneliness

The internet has become increasingly indispensable in daily life for citizens, and the issue of internet addiction has attracted widespread social attention. Internet addiction refers to excessive, uncontrolled internet use, a pathological internet behavior disorder classified as a mental disorder by the World Health Organization in 2018. As the primary users of the internet, college students are also a vulnerable group prone to developing internet addiction, making it a hot topic of international concern. Surveys indicate that China has 1.079 billion internet users, with adolescents accounting for 17.7% of the total. Research indicates that excessive internet use not only increases mental health issues but also leads to academic difficulties and criminal behavior, adversely affecting college students' physical and mental well-being as well as societal development. Among the various factors influencing internet addiction among college students, the positive effects of physical exercise have garnered increasing attention and recognition. However, while considerable research has been accumulated in the field of college student internet addiction, multiple research gaps remain. This study aims to specifically address and expand upon these gaps. Past studies have predominantly focused on internet addiction among college students as a whole, with limited research on students in specific majors. This study targets chemistry majors, whose academic demands—including challenging coursework and high-risk laboratory experiments—result in significantly higher stress perception than those of some humanities and social science majors. Stress is one of the core triggers for internet addiction¹. Previous studies have rarely delved into the internet addiction status of this specific professional group, and this research will fill this gap. Therefore, by thoroughly analyzing the relationships and underlying mechanisms of internet addiction among chemistry majors, this study aims to provide theoretical support for intervention practices using physical exercise to alleviate internet addiction among college students.

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Research hypotheses

Relationship between physical exercise and internet addiction in college students

The phenomenon of internet addiction was first identified by psychiatrist Goldberg² in 1995, who termed it cyber addiction syndrome. It refers to significant impairment in social and psychological functioning resulting from excessive internet use. The adverse predictive effect of physical exercise on internet addiction has been confirmed, with individuals maintaining regular exercise habits exhibiting lower levels of internet obsession. This is closely linked to the improvement in neural and cognitive functions that physical exercise promotes. The displacement hypothesis suggests that, under time-constrained conditions, introducing new activity environments can compel changes in individuals' established behaviors³. Physical exercise strengthens social connections among college students, thereby helping individuals break free from the virtual environment of online social interaction. From physiological and psychological perspectives, exercise improves mood, alleviates fatigue, and boosts energy levels—all of which directly reduce the motivation to escape reality and become immersed in the internet³. In their study, Zhu et al.⁴ implemented a 12-week basketball intervention for a moderately addicted sophomore student, comprising 3–4 sessions per week, each lasting 100–120 min. Evaluations of the student's internet addiction levels before, during, and after the intervention revealed that the student's addiction severity decreased from severe before the experiment to moderate by week 8. By the end of the intervention, the student had returned to a normal range. From a neurobiological perspective, exercise facilitates the release of various neurotransmitters in the central nervous system, including endorphins, dopamine, norepinephrine, and serotonin. The release of these neurotransmitters helps alleviate pain, enhance pleasure and well-being, and significantly promote physical and mental health to a certain extent, thereby reducing internet addiction caused by negative real-life experiences.

Given this, this study proposes Hypothesis H1: Physical exercise has an adverse predictive effect on internet addiction among chemistry majors.

Mediating effect of stress perception

Stress perception refers to the psychological response elicited when an individual cognitively evaluates external environmental stimuli. It also represents an individual's subjective experience of internal and external stressful events, which can alter cognitive functions, emotions, and physiological states⁵. Research indicates that moderate physical activity—such as aerobic exercise, strength training, team sports, and yoga—effectively alleviates students' stress perception, reduces internet addiction behaviors, and helps cultivate perseverance and a positive outlook on life⁶. Zhou Hao posits that appropriate physical exercise accumulates psychological energy, enhancing resilience and adaptability to stress⁷. Furthermore, extensive empirical research indicates that college students' stress perception positively predicts internet addiction⁸. A longitudinal study revealed that stressful life events significantly predict increased internet addiction symptoms one year later, demonstrating that stress is not only an immediate trigger but also carries long-term negative consequences. According to Kardefelt-Winther's compensatory internet use model, individuals turn to the internet to self-regulate and compensate for life stressors and negative emotions. Prolonged use increases tolerance to internet activity, ultimately forming internet addiction¹. Chemistry majors face unique academic pressures, and physical exercise, as a positive coping mechanism, can effectively alleviate this stress. Reduced stress diminishes the need to escape reality through internet addiction.

Given this, this study proposes Hypothesis H2: Stress perception mediates the relationship between physical exercise and internet addiction among chemistry majors.

The mediating effect of loneliness

Loneliness refers to the negative experience arising from an individual's subjective perception that their actual social interactions fall short of their desired state⁹. As a common psychological issue, it impacts college students' physical and mental health¹⁰, ranging from diminished well-being and impaired academic/social functioning to severe consequences like depression and suicidal behavior¹¹. Research indicates that physical exercise can alleviate loneliness among college students by enhancing social self-efficacy¹². Self-determination theory posits that unmet psychological needs heighten an individual's fear of deprivation¹³. Since social media serves as an effective tool for fulfilling social psychological needs, it often becomes a primary avenue for alleviating this fear of deprivation. Furthermore, individuals experiencing higher levels of loneliness tend to seek fulfillment of their social needs through online social media¹⁴. Social compensation theory posits that individuals experiencing social deprivation in real-world settings turn to online platforms to substitute for it. For chemistry majors, demanding coursework and laboratory work may exacerbate loneliness. Physical exercise, particularly team sports, can directly alleviate loneliness by increasing real-world social interactions and enhancing a sense of belonging¹⁵. Conversely, higher loneliness levels increase students' preference for online socializing, seeking emotional support through the internet, or even using it as an escape from real-world loneliness—all significantly elevating internet addiction risk. Thus, physical exercise likely reduces internet addiction by effectively lowering loneliness, thereby decreasing internet use driven by social compensation and escapism motives¹⁶.

Given this, the present study proposes Hypothesis H3: Loneliness mediates the relationship between physical exercise and internet addiction among chemistry majors.

Chain mediation effect of stress perception and loneliness

Stress perception refers to an individual's subjective experience of pressure, whose effects span psychological, physiological, and behavioral dimensions. Its influence on loneliness manifests through dual pathways: cognitive distortions and social withdrawal. The greater the stress perception, the more likely individuals are to actively or passively distance themselves from others, ultimately becoming trapped in a vicious cycle of loneliness. Research indicates that stress perception positively predicts loneliness¹⁷. Push–Pull Theory posits

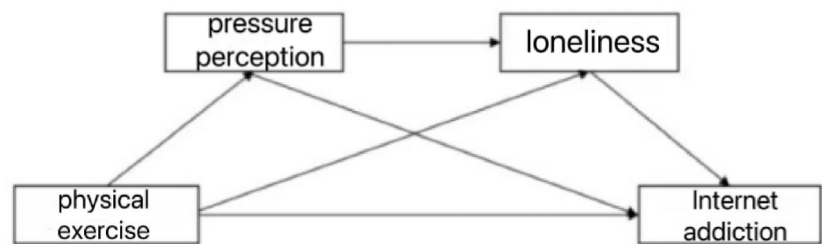


Fig. 1. Conceptual model diagram.

Demographic variables	Categorization	Number of people	Percentage (%)
Gender	Male	449	49.8
	Women	451	50.2
Grade	First year	220	24.4
	Sophomore year	220	24.4
	Junior year	235	26.2
	Senior year	225	25.0
Place of origin of students	Countryside	385	42.7
	Municipalities	515	57.3
Only child	Be	500	55.56
	Clogged	400	44.44

Table 1. Basic information of survey respondents (N = 900).

that stressors can function as push factors. When fundamental needs—such as desired quality of life, security, and developmental opportunities—remain unmet in one’s environment, psychological pressure and an urge to escape emerge¹⁸. In such circumstances, individuals may perceive a disconnect with their surroundings, which can foster feelings of loneliness. Previous research indicates that heightened stress impacts an individual’s sense of self, leading to increased experiences of loneliness and depression. Over time, this can severely compromise mental health¹⁹. Social cognitive Theory posits that an individual’s cognitive assessment of stress influences their behavior and emotions. When an individual’s actual social status fails to align with their internal expectations, it becomes difficult to form emotional connections with others, which can trigger feelings of loneliness²⁰. Related studies also provide evidence that stress perception positively predicts loneliness. A one-year longitudinal study involving 742 college students found that after intervention, students’ stress perception and loneliness were positively correlated, with both dimensions of tension and lack of control within stress perception influencing loneliness²¹.

Based on this, this study proposes Hypothesis H4: Stress perception and loneliness exert a chain-mediated effect on the relationship between physical exercise and internet addiction.

In summary, this study introduces stress perception and loneliness as mediating factors in the relationship between physical exercise and internet addiction, constructing the chained mediation model depicted in Fig. 1. The following aspects will be verified: (1) Physical exercise significantly and negatively predicts internet addiction; (2) Stress perception and loneliness independently mediate the relationship between physical exercise and internet addiction; (3) Stress perception and loneliness mediate in a chain-like manner between physical exercise and internet addiction among chemistry majors.

Procedures

Participants

This survey has been jointly approved by school administrators, faculty, and participants. The survey sample comprises 900 undergraduate chemistry majors from Liaoning, Heilongjiang, and Jilin provinces in China, spanning all four academic years from freshman to senior level. This sample accurately reflects the actual circumstances of this population. Basic information regarding the selected research topics is detailed in Table 1.

Research participants and methods

Participants and sampling

Using convenience sampling, 917 chemistry majors from 11 universities in Liaoning, Heilongjiang, and Jilin provinces completed the physical exercise rating scale, internet addiction scale, stress perception scale, and loneliness scale to investigate the mediating effect between physical exercise and internet addiction. Invalidated and discarded were questionnaires exhibiting any of the following issues: (1) inconsistent responses to reverse-scored items; (2) abnormally short completion time (under 70 s); (3) patterned responses. Exclusions included three questionnaires with inconsistent reverse-scored item responses, 11 with abnormally short completion times, and 3 with patterned responses. Ultimately, 900 valid questionnaires were collected, yielding a 98%

response rate. The sample comprised 449 males (49.8%) and 451 females (50.2%) college students. All 900 respondents actively participated in physical exercise and understood the concepts of internet addiction, stress perception, and loneliness.

To ensure sample suitability for the research topic, this study established clear participant selection criteria as follows:

1. **Identity Matching Criteria:** Limited to undergraduate chemistry majors enrolled in universities within Liaoning, Heilongjiang, and Jilin provinces, China. This ensured the research subjects were focused on a specific disciplinary group, avoiding additional interference from disciplinary backgrounds in core variables such as physical exercise behavior and internet usage scenarios. This aligns closely with the study's objective of exploring the relationship between physical exercise and internet addiction among chemistry majors.
2. **Cognitive and Behavioral Foundation Criteria:** Participants were required to actively engage in physical exercise and accurately comprehend the concepts of internet addiction, stress perception, and loneliness.
3. **Data Quality Screening Criteria:** Following questionnaire collection, invalid samples were further eliminated through a triple-rule screening process. Both the sample structure and screening procedures met the pre-defined participant selection criteria, providing a reliable data foundation for subsequent analyses of mediating effects.

Physical exercise rating scale

Research tools

Revised by Liang Deqing et al. this scale assesses physical exercise volume through three dimensions: intensity, duration per session, and weekly frequency. It demonstrates high reliability and validity. Higher total scores on a 5-point Likert scale indicate greater exercise volume. Scoring formula: $\text{Exercise Volume} = \text{Intensity} \times (\text{Time} - 1) \times \text{Frequency}$, ranging from 0 to 100 points. In this study, the scale demonstrated good reliability and validity. Its internal consistency reliability, as measured by the α coefficient, was 0.836.

Internet addiction scale

The Chinese Internet Addiction Scale Revised Edition, developed by Bai Yu, Fan Fumin, et al. was used. It comprises 19 items organized into four dimensions: compulsive internet use and withdrawal symptoms, tolerance to internet use, interpersonal and health problems, and time management issues. For example: "More than once, someone has told me I spend too much time online." All items were scored on a 4-point scale ranging from Strongly Disagree to Strongly Agree. The total score reflects an individual's level of internet addiction, with higher scores indicating a greater likelihood and tendency toward internet addiction. In this study, the scale demonstrated good reliability and validity. The internal consistency reliability coefficient was 0.879.

Stress perception scale

The revised Stress Perception Scale by Yang, Tingzhong et al. comprising 14 items, was used. This scale consists of two dimensions: sense of loss of control (e.g., In the past month, I felt that things went my way) and sense of tension (e.g., In the past month, I felt upset by unexpected events). Items 4, 5, 6, 7, 9, 10, and 13 are reverse-scored. Scoring follows a 5-point Likert scale: forward-scored items range from 1 (never) to 5 (always), while reverse-scored items are scored in reverse. After assigning positive values to reverse items, scores for each dimension are summed to yield the total stress perception Scale score. Higher scores indicate greater individual stress. In this study, the scale demonstrated good reliability and validity. Its internal consistency reliability, as measured by the coefficient, was 0.917.

Loneliness scale

The loneliness scale developed by Russell was employed. This 20-item questionnaire uses a 4-point scale (Never, Rarely, Sometimes, Always) to measure adolescents' loneliness stemming from the gap between their ideal and actual interpersonal relationships. For example, "Do you feel like you belong among your friends?" Higher final scores indicate greater loneliness. In this study, the scale demonstrated good reliability and validity. The internal consistency reliability α coefficient was 0.876.

Data statistics and analysis

Initial data organization and analysis were conducted using SPSS 27.0, including common-method bias assessment, independent-samples t-tests, one-way ANOVA, Pearson correlation analysis, and regression analysis. Second, the variance-maximizing maximum likelihood method was employed to validate model fit indices, and bootstrap percentiles with bias correction were used to test mediation effects. Finally, a chained mediation model was constructed. Additionally, the G*Power analysis software was used to calculate the sample size for the questionnaire survey. The effect size was set at 0.3, the significance level at 0.05, and the statistical power at 0.8, yielding a required sample size of 82. The final sample size for this study was 900, significantly exceeding the 82 required by G*Power analysis. This decision was made to enhance statistical power and precision, as a larger sample size allows estimates to better approximate the actual population parameters and reduces sampling error.

Research findings

Common method bias test

Common method bias is one form of systematic error in constructing mediation models. Given that this study's data were collected via questionnaire surveys, results may be potentially affected by common method bias. Therefore, the Harman single-factor test was primarily employed to identify common method bias issues. Results

	Gender	Number	M ± SD	F	P
Physical exercise	Male	449	3.00 ± 0.97	17.321	0.000**
	Women	451	2.75 ± 0.84		
Internet addiction	Male	449	2.07 ± 0.56	10.377	0.001**
	Women	451	2.19 ± 0.52		
Stress perception	Male	449	2.88 ± 0.56	12.722	0.000**
	Women	451	3.00 ± 0.47		
Loneliness	Male	449	2.26 ± 0.46	1.479	0.000**
	Women	451	2.30 ± 0.38		

Table 2. Gender differences between different variables. N = 900. * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.

	Grade	Number	M ± SD	F	p
Physical exercise	Freshman	220	2.62 ± 0.91	14.142	0.000**
	Sophomore	220	2.80 ± 0.89		
	Junior	235	3.15 ± 0.91		
	Senior	225	2.91 ± 0.88		
Internet addiction	Freshman	220	2.19 ± 0.52	6.026	0.000**
	Sophomore	220	2.20 ± 0.48		
	Junior	235	2.01 ± 0.59		
	Senior	225	2.13 ± 0.54		
Stress perception	Freshman	220	2.99 ± 0.52	2.712	0.000**
	Sophomore	220	2.97 ± 0.42		
	Junior	235	2.86 ± 0.61		
	Senior	225	2.96 ± 0.50		
Loneliness	Freshman	220	2.30 ± 0.44	2.279	0.000**
	Sophomore	220	2.32 ± 0.34		
	Junior	235	2.22 ± 0.47		
	Senior	225	2.29 ± 0.41		

Table 3. Differences in grade levels between variables. N = 900. * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.

	1	2	3	4
Physical exercise	1			
Internet addiction	− 0.290**	1		
Stress perception	− 0.060	0.355**	1	
Loneliness	− 0.006	0.237**	0.467**	1

Table 4. Correlation analysis between variables. N = 900. * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.

revealed five factors with eigenvalues exceeding 1. The first factor explained 30.1% of the variance, significantly below the 40% critical threshold (Podsakoff et al. 2003), indicating no common method bias in the data.

Descriptive statistics and correlation analysis of variables

Independent samples t-tests were used to analyze gender differences in physical exercise, internet addiction, stress perception, and loneliness. Results showed significant differences, with male college students performing better than female college students (see Table 2).

A one-way ANOVA was used to compare differences in physical exercise, internet addiction, stress perception, and loneliness across grade levels. Test results show that, as indicated in Table 3, significant differences exist in physical exercise levels across grade levels, with juniors exhibiting the highest levels and first-year students the lowest, indicating that upper-level students engage in more active exercise overall. Significant differences in internet addiction levels were also found across grade levels, with sophomores showing the highest levels and juniors the lowest. Significant differences in stress perception were observed across grade levels, with seniors reporting the highest levels of stress. Similarly, significant differences in loneliness were observed across grades, with sophomores reporting the highest levels (see Table 3).

A Pearson correlation analysis was conducted on all variables to examine potential relationships among physical exercise, internet addiction, stress perception, and loneliness. As shown in Table 4, significant negative

Outcome variable	Predictor variable	Fitness index			Significance of the coefficient	
		R	R ²	F	β	t
Stress perception	Grade	0.016	0.013	4.894	− 0.016	− 0.462
	Sexe				0.110	3.250
	Physical exercise				− 0.042	− 1.249
Loneliness	Grade	0.219	0.215	62.687	− 0.020	− 0.668
	Sexe				− 0.015	− 0.494
	Physical exercise				− 0.023	0.763
	Stress perception				0.469	15.749
Internet addiction	Grade	0.089	0.086	29.126	− 0.021	0.510
	Sex				0.065	0.045
	Physical exercise				− 0.277	− 8.539
	Stress perception				0.289	8.516
	Loneliness				0.098	2.919

Table 5. Regression analysis of physical exercise, stress perception, and loneliness on internet addiction. N = 900 * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.

Trails	Efficiency value	Boot SE	95% confidence interval	
			BootLLCI	BootULCI
Aggregate effect	− 0.171	0.019	− 0.208	− 0.134
Direct effect	− 0.160	0.018	− 0.195	− 0.126
Path 1	− 0.010	0.011	− 0.041	0.005
Path 2	− 0.001	0.003	− 0.004	0.009
Path 3	− 0.002	0.002	− 0.007	0.001
Total indirect effect	0.240	0.022	0.236	0.323

Table 6. Mediated effects test.

correlations were found among physical exercise, stress perception, and loneliness ($p < 0.01$), indicating that higher levels of physical exercise are associated with lower stress perception, loneliness, and internet addiction. Thus, Hypothesis H1 is supported. The strong, significant correlations among variables indicate suitability for subsequent mediation effect analysis and support further hypothesis testing.

Given the strong correlations among all variables, multicollinearity may be present, potentially leading to unstable results. Therefore, this study conducted collinearity diagnostics and standardized all predictor variables (Z-scores) in each subsequent equation. Results showed that all variance inflation factors (VIF) for predictor variables (1.097–1.291) were below 5. Thus, no multicollinearity was present, meeting the conditions for testing chained mediation effects.

Using physical exercise as the independent variable, stress perception and loneliness as mediating variables, and internet addiction as the dependent variable, the PROCESS macro program (SPSS plugin provided by Hayes, 2013) was employed. Model 6 (chain mediation) was adopted, with grade and gender as control variables. The chain mediation model effect was tested using Bootstrap Samples set to 5000, with a default 95% confidence interval. Results indicated that physical exercise significantly predicted internet addiction among chemistry majors, even before mediating variables were included. After incorporating mediating variables, physical exercise continued to significantly predict internet addiction among these students. Specifically, the path coefficient (β) for physical exercise on stress perception was − 0.042, while the path coefficient for stress perception on internet addiction was 0.289. The path coefficient for physical exercise on loneliness was − 0.023, the path coefficient for loneliness on internet addiction was 0.098, and the path coefficient for stress perception on loneliness was 0.469 (Table 5).

Mediation effects were tested using bootstrap sampling with bias correction. As shown in Table 6, the total mediation effect was − 0.171, and the bootstrap 95% confidence interval did not contain zero. This indicates a significant total mediating effect of physical exercise on internet addiction among chemistry majors. The total mediating effect comprises three paths: Ind1: “physical exercise → stress perception → internet addiction” with an effect value of − 0.010; Ind2: “physical exercise → loneliness → internet addiction” with an effect value of − 0.001; Ind3: “physical exercise → stress perception → loneliness → internet addiction” with an effect value of − 0.002. The Bootstrap 95% confidence intervals for all three paths exclude zero, confirming significant chained mediating effects. These results respectively validate Hypotheses 2, 3, and 4.

Discussion

To explore the underlying mechanisms through which physical exercise influences internet addiction among chemistry majors, this study constructed and validated a chained mediation model incorporating stress perception and loneliness as mediating variables. Findings reveal the internal mechanisms by which physical exercise affects internet addiction in chemistry majors, while also providing empirical evidence for reducing internet addiction behaviors and promoting mental health among university students.

Relationship between physical exercise and internet addiction

This study found a significant negative correlation between physical exercise and internet addiction among chemistry majors ($r = -0.290$). After controlling for variables and incorporating mediating variables, the adverse predictive effect of physical exercise on internet addiction remained significant ($p < 0.001$). According to Cohen's effect size criteria, this represents a small-to-medium effect. While the findings indicate that higher levels of physical exercise correlate with lower tendencies toward internet addiction among university students, physical exercise alone explains only a limited portion of the variance in internet addiction. Therefore, while acknowledging its statistical significance, we should cautiously assess its practical influence. These findings align with the displacement hypothesis, which posits that individuals who devote more time to physical exercise satisfy their personal needs, thereby reducing dependence on the internet and, to some extent, preventing internet addiction behaviors³. Physical exercise effectively mitigates internet addiction behaviors. For instance, Zhu Li's research revealed that adolescents with internet addiction exhibited significant improvements in their addictive behaviors after engaging in physical exercise⁴. During exercise, college students can interact with peers, thereby increasing exercise frequency and fostering healthy lifestyle habits⁴. Additionally, research indicates that varying exercise intensities and frequencies exert distinct effects on college students' internet addiction. High-intensity exercise rapidly stimulates increased neurotransmitter release in the brain, elevating mood states and potentially offering quicker suppression of internet addiction. Conversely, low-intensity exercise may gradually improve students' psychological states through long-term, subtle physical and mental regulation, progressively reducing internet use time²². Moreover, exercise frequency is crucial. Frequent short-duration workouts may help students establish exercise habits and sustain positive psychological states. At the same time, weekly long-duration sessions might focus on stress relief within specific timeframes, reducing students' psychological dependence on the internet²³.

Mediating role of stress perception

The findings of this study indicate that mediating variables play a significant role in explaining the impact of physical exercise on college students' internet addiction, consistent with previous research⁶. This study found that lower-year students exhibit higher levels of stress perception than upper-year students. Analysis suggests this may stem from lower-year students' recent transition to university life and their ongoing adolescence, during which psychological development remains immature. Additionally, significant differences between university and high school environments—including learning and living patterns—can lead to maladaptive responses to stressful events⁷. Simultaneously, because the internet is escapist and compensatory, individuals tend to retreat into virtual networks when confronted with unmanageable or unsatisfying real-life situations. They seek fulfillment through online behaviors, which, over time, leads to regression in real-world social functioning and the development of internet addiction¹. Numerous studies have examined the mechanisms through which physical exercise influences college students' internet addiction. According to general stress theory, exercise significantly improves emotional states by promoting the release of beneficial chemicals, such as endorphins and brain-derived neurotrophic factor (BDNF)—often called “feel-good hormones.” These substances regulate the emotional center, inducing pleasure and effectively alleviating stress and negative emotions⁸. While some studies suggest “lower-year students benefit more from exercise interventions for internet addiction,” this research found “upper-year students exhibit higher exercise motivation and lower internet addiction levels.” This discrepancy may stem from the characteristics of chemistry education: lower-year students, newly exposed to complex theories and experiments, face adaptation pressures that divert energy from study and heighten reliance on online social networks; Senior students, however, develop more structured time management skills through prolonged specialized study. Confronted with concrete goals like graduation and employment, they are more inclined to regulate their state through exercise, thereby reducing meaningless internet usage. Although this pathway is statistically significant, its effect size is relatively small. This indicates that the pathway of reducing stress perception through physical exercise, which in turn decreases internet addiction, exists but may not be the most substantial overall influence.

Mediating role of loneliness

This study confirms that loneliness mediates the relationship between physical exercise and internet addiction among chemistry majors, consistent with previous research. The effect size of this pathway is relatively small. This implies that the mechanism whereby physical exercise reduces internet addiction by alleviating loneliness is valid, but its effect is gradual and limited. Research indicates that physical exercise not only maintains physical health but also gradually improves adolescents' psychological state and addresses psychological issues. Students who frequently engage in exercise exhibit weaker loneliness¹¹. Additionally, individuals engaging in moderate-intensity exercise three or more times per week scored 23% lower on loneliness measures compared to sedentary peers, with high-intensity exercisers showing even more pronounced reductions. This may stem from high-intensity workouts stimulating the release of neurotransmitters like endorphins and dopamine, which enhance mood, alleviate stress, and foster a more positive disposition for social engagement. After activities like running or basketball, individuals often experience a “post-exercise high” that makes them more willing to engage with others¹². Furthermore, high-intensity exercise demands time and energy, objectively reducing opportunities for

rumination during solitary periods. When focused on physical exertion, subjective perceptions of loneliness are diminished¹⁶. Self-determination theory posits¹³ that lonely individuals often experience deficits in autonomy, competence, and relatedness due to social setbacks in real life. The internet provides compensatory scenarios: gaming satisfies competence needs through task completion and level progression; social platforms offer virtual validation via likes and comments, alleviating relatedness deficits. This fills psychological gaps, creating a cycle of “need deficit–online fulfillment–dependency reinforcement”¹⁴. Furthermore, while some studies suggest that “loneliness is most pronounced among juniors,” this research indicates that “seniors experience the highest levels of loneliness.” This is speculated to be related to the extended time required for seniors in chemistry programs to complete graduation thesis experiments, reduced social activities, and heightened psychological loneliness stemming from increased uncertainty about future careers. This also suggests that the unique characteristics of specialized training phases may influence the developmental trends of psychological variables.

Chain mediation effect of physical exercise on internet addiction

The Bootstrap method validated the chained mediating role of stress perception and loneliness in the relationship between physical exercise and internet addiction among chemistry majors. The constructed chained mediation model offers new perspectives for advancing and understanding the relationship between physical exercise and internet addiction among college students. Stress perception refers to an individual's subjective appraisal of stressful situations, i.e., “the level of stress one feels.” It is not the objective stress event itself, but rather the individual's subjective experience of stress. For example, when facing the same exam, some may feel “able to handle it easily,” while others may feel “anxious to the point of collapse.” This difference reflects the perception of stress. The results of this study indicate that the perception of stress among chemistry majors is significantly positively correlated with loneliness. The higher the perception of stress among college students, the greater their loneliness, consistent with domestic and international research findings¹⁷. Chemistry majors often experience prolonged solitary laboratory work, coupled with pressures from experimental failures and publication expectations (high stress perception), leading to online escapism to avoid real-life challenges. This study confirms that physical exercise can simultaneously alleviate both core stressors, proving more suitable than single interventions (e.g., counseling alone) for this group's practical needs of “fragmented time and the necessity to balance academics with emotional regulation.” Existing research indicates that stressors such as life events, interpersonal conflicts, and family dysfunction among college students can induce stress. When individuals face stressful environments, those with higher loneliness levels are more prone to negative and pessimistic cognitions about events, making it challenging to regulate negative emotions and leading to maladaptive outcomes¹⁰. Social cognitive theory posits that when individuals perceive stress as threatening, they may actively avoid social interactions, leading to social isolation and intensifying loneliness²⁰.

Limitations, future prospects, and recommendations

This study explores the relationship between physical exercise and internet addiction among chemistry majors. Constructing a chain mediation model reveals the underlying mechanism through which physical exercise influences internet addiction in chemistry majors, offering new perspectives and insights. This holds significant theoretical and practical implications for reducing internet addiction among chemistry majors. However, the study has several limitations:

- (1) First, the study sample consisted of chemistry majors from universities in Liaoning, Jilin, and Heilongjiang provinces, excluding students from other regions, disciplines, and groups. The representativeness and generalizability of the findings require further expansion. Future research should broaden the scope by selecting a more diverse sample to examine the applicability of these conclusions.
- (2) Secondly, this study employed convenience sampling, with the sample drawn exclusively from chemistry majors at one or a few universities. While this sampling method is feasible in practice, it limits the external validity of the findings to some extent. The findings may apply only to groups with characteristics similar to those of the study sample and cannot be directly generalized to all chemistry majors. They should not be rashly extrapolated to students in other majors, regions, or with different cultural backgrounds. Convenience sampling may result in uneven distribution across variables such as gender, grade level, academic performance, and university type, thereby failing to represent a broader population. Future research should employ more rigorous random sampling or stratified cluster sampling to draw larger, more representative samples from institutions across different regions and tiers nationwide. This would validate the model's generalizability and explore potential subgroup differences (e.g., urban/rural students, students from different socioeconomic backgrounds). Furthermore, existing research reports only small effect sizes for indirect pathways (e.g., “physical exercise → loneliness → internet addiction,” with values such as -0.001) without delving into the reasons. For instance, it remains unexamined whether the effects were underestimated or weakened by factors such as “insufficient intervention duration,” “mismatched exercise forms targeting specific mechanisms,” or “the presence of inhibitory confounding variables.” Although this study focuses on the relationships among physical exercise, internet addiction, stress perception, and loneliness, it may still overlook uncontrolled variables such as anxiety, depression, social support, and sleep habits—all of which could influence internet addiction levels as well as stress and loneliness.
- (3) Furthermore, this cross-sectional design limits the ability to establish causal relationships and imposes constraints on interpreting variable interactions. For instance, while the study found that stress perception positively predicts loneliness among chemistry majors—consistent with prior research—this association may be influenced by other uncontrolled variables. Moving forward, the team will conduct longitudinal tracking studies to further investigate the long-term mechanisms through which stress perception influenc-

- es loneliness among chemistry majors, thereby scientifically and accurately elucidating causal relationships among variables.
- (4) Finally, the potential impact of self-reporting bias in questionnaires. This study relies entirely on self-reporting for data collection. All variables (physical exercise, stress perception, loneliness, and internet addiction) were measured through scales completed by participants. While efficient and convenient, this approach may be susceptible to common method bias. Participants may be influenced by social desirability, current emotional states, or default response styles when completing questionnaires, potentially distorting the genuine relationships between variables. Although we employed measures such as anonymity, reverse-scoring certain items, and a post-hoc Harman's single-factor test, the potential impact of standard-method bias cannot be entirely ruled out. Future research may address this issue through multi-source, multi-method data collection. For instance, fitness trackers could objectively record exercise data, counselors or peers could assess manifestations of loneliness, or clinical interviews could diagnose the severity of internet addiction—thereby capturing variables more comprehensively.
 - (5) Practical recommendations based on research findings
 1. Establish a “Major + Grade Level” Tiered Exercise System: Addressing the characteristics of “higher exercise motivation among upper-level students and peak internet addiction/stress perception among freshmen,” mandate exercise health courses for first-year students while offering graduation season stress-relief exercise packages for seniors to precisely match grade-level needs.
 2. Targeted interventions for key groups: Prioritize first-year chemistry majors (highest rates of internet addiction and stress perception) and seniors (highest levels of loneliness). Conduct monthly class meetings to share exercise-based stress relief case studies and develop personalized exercise plans for students exhibiting internet dependency tendencies.

Data availability

The data presented in this study are available on request from the corresponding author.

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Author contributions

Y.L. designed the study, collected and analyzed the data, and wrote the manuscript. Y.L. wrote and translated. Y-W Y responsible for inspection and drafting. Y.L. (corresponding author) investigated and revised the manuscript. All authors have read and finalized the final manuscript and contributed equally to the paper.

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Declarations

Ethical approval and consent to participate

The design of this study followed the guiding principles and provisions of the Declaration of Helsinki and was approved by the Ethics Committee of Liaoning Normal University (LL2025145), with all participants signing an informed consent form.

Consent to participate

Informed consent was obtained from all individuals participating in the study.

Competing interests

The authors declare no competing interests.

Consent for publication

Not applicable.

Additional information

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