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The relationship between physical exercise and social media addiction among Chinese university students: a random intercept cross-lagged panel model analysis

Yuantai Fu^{1,2}, Jiaqi Wang³, Renchun Liang⁴, Caixia Li⁵ and Jian Sun^{1*}

Abstract

Background In the digital era, Social Media Addiction has emerged as a prominent issue affecting the mental health of university students. Despite evidence linking physical exercise to lower Social Media Addiction, it remains unknown whether within-person changes in physical exercise actually predict subsequent changes in Social Media Addiction, and whether psychological resilience accounts for this link. Prior work is constrained by cross-sectional designs, the absence of a unified model integrating these three constructs, and reliance on traditional cross-lagged panel models that cannot separate between-person from within-person effects.

Objective This study employed a random intercept cross-lagged panel model (RI-CLPM) to examine the longitudinal relationships between physical exercise and Social Media Addiction among university students, and to test the mediating role of psychological resilience.

Methods A three-wave longitudinal study was conducted with 632 university students ($M_{age} = 20.29$, $SD = 0.86$) from two universities in China, with data collected in January 2025, July 2025, and January 2026.

Results At the between-person level, physical exercise was negatively associated with Social Media Addiction ($\beta = -0.571$). At the within-person level, bidirectional relationships were identified: physical exercise negatively predicted subsequent Social Media Addiction ($\beta = -0.199$ to -0.138), while Social Media Addiction negatively predicted subsequent physical exercise ($\beta = -0.146$ to -0.242). Psychological resilience significantly mediated the effect of physical exercise on Social Media Addiction ($\beta = -0.115$), but the reverse pathway was not significant.

Conclusion Physical exercise and Social Media Addiction demonstrate a reciprocal relationship at the within-person level, with psychological resilience serving as a significant mediator. Universities should integrate physical exercise into mental health promotion strategies to prevent Social Media Addiction.

Keywords Physical exercise, Social Media Addiction, Psychological resilience, University students

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Introduction

In the digital era, social media has become deeply integrated into the daily lives of university students. Statistical evidence indicates that university students constitute one of the most active user groups on social media platforms, and their high-frequency, prolonged usage patterns have prompted considerable scholarly attention to the issue of Social Media Addiction [1]. Social Media Addiction refers to a maladaptive use behavior characterized by individuals' excessive preoccupation with social media, accompanied by substantial investment of time and effort, to the extent that it impairs their physical and mental health as well as social functioning [2]. Growing evidence links Social Media Addiction to negative psychological and functional outcomes among university students, including depression, anxiety, sleep disturbances, and reduced academic engagement [3–5]. Given the detrimental effects of Social Media Addiction on students' psychological well-being, an in-depth investigation of its underlying psychological mechanisms holds significant theoretical and practical implications.

Physical exercise, as an important behavioral approach to promoting mental health and overall well-being, has received consistent empirical support from a substantial body of high-quality research regarding its positive intervention value. Singh et al. [6] published the most comprehensive umbrella review to date, synthesizing 97 systematic reviews, and found that physical exercise yielded moderate ameliorative effects on depressive and anxiety symptoms, with these benefits remaining robust across varied populations, including healthy individuals, those with psychiatric diagnoses, and patients suffering from chronic illnesses. Zhang et al. [7] further corroborated these findings in a study of 1,117 Chinese university students, demonstrating significant negative correlations between physical exercise levels and negative affective states (i.e., depression, anxiety, and stress). Together, these findings highlight physical exercise as a promising intervention for promoting mental health among university students.

A growing body of research has explored the association between physical exercise and Social Media Addiction behaviors [8, 9]. According to the behavioral substitution perspective, these two activities are in competition for individuals' time resources [10]. A cross-cultural comparative study of 1,500 university students from ten universities across China revealed a parallel inverse pattern, with regions reporting more frequent social media use also showing lower levels of physical exercise [11]. In addition, the motivation for social media engagement lies in meeting psychological needs such as social belonging, self-expression, and emotion regulation [12], whereas physical exercise can similarly satisfy these psychological needs through pathways including

social interaction, enhanced self-efficacy, and positive affective experiences [13]. Taken together, physical exercise demonstrates considerable theoretical potential for preventing and reducing Social Media Addiction among university students; however, studies examining the longitudinal relationship between these two variables remain notably scarce.

Among the psychological mechanisms underlying the effect of physical exercise on Social Media Addiction, psychological resilience is likely to play a critical mediating role. Psychological resilience refers to a dynamic process whereby individuals effectively adapt and maintain psychological functioning when confronted with adversity, trauma, or significant stressors [14]. Resilience is essentially a dynamic psychological resource that can be enhanced through external experiences (e.g., physical exercise) [15] while simultaneously functioning as a protective factor that shapes individuals' behavioral choices [16]. Prior empirical studies have established a significant positive correlation between physical exercise and psychological resilience [15]. With respect to the resilience–Social Media Addiction relationship, existing evidence has shown that highly resilient individuals typically possess stronger emotion regulation skills and employ more adaptive coping strategies [17]. Consequently, these individuals are more inclined to utilize adaptive rather than maladaptive strategies (e.g., excessive social media engagement) in response to stress or negative affect. Empirical evidence has indicated significant negative correlations between psychological resilience and Social Media Addiction [18, 19], supporting the protective function of resilience against addictive behaviors.

The current literature has several limitations. First, prior studies on the relationship between physical exercise and Social Media Addiction have relied primarily on cross-sectional designs, which preclude the exclusion of confounding effects attributable to stable inter-individual differences and fail to elucidate the longitudinal predictive relationships among variables across time [20]. Second, limited research has concurrently examined physical exercise, psychological resilience, and Social Media Addiction within a unified analytical framework. While previous studies have confirmed that psychological resilience mediates the association between physical exercise and general internet addiction [21, 22], Social Media Addiction represents a specific subtype of internet addiction characterized by unique socially driven mechanisms; whether the proposed mediating pathway similarly applies to this context remains empirically unverified, particularly through longitudinal investigation. Third, although some longitudinal studies using traditional CLPMs have provided preliminary evidence [23], this approach has a key limitation: it conflates

between- and within-person variance, which may lead to erroneous inferences [24].

In response to these limitations, the present study utilized a Random Intercept Cross-Lagged Panel Model (RI-CLPM) with three-wave longitudinal data spanning one year to comprehensively examine the temporal relationships among physical exercise, psychological resilience, and Social Media Addiction among university students. The RI-CLPM incorporates random intercepts to decompose stable individual differences at the trait level from time-varying fluctuations within individuals, thereby facilitating more accurate estimation of within-person cross-lagged predictive relationships. This methodological innovation allows us to address the following critical questions: After controlling for stable between-person differences, do within-person fluctuations in physical exercise longitudinally predict changes in Social Media Addiction? Does psychological resilience mediate this relationship [24]?

Based on the foregoing theoretical analysis, the present study proposed the following hypotheses:

Hypothesis 1 Physical exercise is significantly negatively associated with Social Media Addiction at the between-person level.

Hypothesis 2 At the within-person level, physical exercise and Social Media Addiction exhibit bidirectional relationships, with each negatively predicting the other over time (H2a and H2b, respectively).

Hypothesis 3 At the within-person level, psychological resilience mediates both the pathway from physical exercise to Social Media Addiction (H3a) and the reverse pathway (H3b).

From a theoretical perspective, this study contributes to the literature by integrating health behavior and digital addiction research, clarifying how salutogenic factors such as psychological resilience may protect against problematic social media use among undergraduates. Furthermore, by applying a random-intercept cross-lagged panel model, this study separated stable between-person differences from time-varying within-person fluctuations, making it possible to examine whether, once stable between-person differences are removed, an increase in a student's own level of physical exercise predicts a subsequent decline in that same student's Social Media Addiction. It is precisely this within-person temporal dynamic, together with the identification of resilience as a within-person mediating mechanism, that moves this study beyond the largely cross-sectional and traditional cross-lagged evidence of prior research. The practical implications suggest that university interventions targeting Social Media Addiction should not be

confined to restricting usage duration or strengthening behavioral monitoring; rather, greater emphasis should be placed on fostering psychological resilience development among university students through sustained physical exercise engagement, thereby providing a more positive developmental orientation for promoting digital health among this population.

Methods

Participants and procedure

This study utilized a longitudinal design comprising three measurement waves and obtained ethical approval from the local ethics committee (Approval No.: XH250124-01). A total of 632 university students ($M_{\text{age}} = 20.29$, $SD = 0.86$) were recruited from two universities in China as the initial sample, with 381 participants from one university and 251 from the other. The sample comprised 345 male (54.6%) and 287 female (45.4%) students; in terms of year of study, 94 (14.9%) were first-year, 101 (16.0%) second-year, 375 (59.3%) third-year, and 62 (9.8%) fourth-year students. Data were collected in January 2025 (T1), July 2025 (T2), and January 2026 (T3), yielding valid sample sizes of 632, 619, and 605 participants at the three time points, respectively.

Data were collected via offline administration. Prior to participation, research assistants explained the study objectives and procedures, assured participants of data confidentiality and anonymity, and confirmed that responses would be used exclusively for research purposes. After fully understanding the aforementioned information, all participants provided written informed consent. Each survey session lasted approximately 30 min. The study adopted an item-to-response ratio of 1:5 [25], which necessitated a minimum sample of 75 participants for the 15 assessment items. Little's MCAR test was performed on the composite scores of physical exercise, psychological resilience, and Social Media Addiction at each of the three waves, together with the two covariates (gender and age), yielding 11 variables in total [26]. The test was non-significant ($\chi^2 = 8.441$, $df = 13$, $p = 0.814$), supporting the assumption that data were missing completely at random.

Measures

Three validated instruments were administered across all measurement waves. Psychological resilience was evaluated via the Brief Resilience Scale [27], a six-item self-report inventory assessing individuals' capacity to recover from stressful experiences, with responses recorded on a 5-point Likert format (Cronbach's $\alpha = 0.865$, 0.857 , and 0.861 for Waves 1–3, respectively). Problematic social media use was captured using the Bergen Social Media Addiction Scale [28], which operationalizes six core addiction components—salience,

mood modification, tolerance, withdrawal, conflict, and relapse—through six items rated on a 5-point scale ($\alpha = 0.867, 0.846, \text{ and } 0.852$ across the three assessments). Habitual physical exercise was quantified with the Physical Activity Rating Scale-3 [29], which appraises exercise behavior along three dimensions: intensity, duration, and frequency, each scored on a 5-point metric. A composite score was derived using the formula: Physical exercise = Intensity $\times$ (Duration – 1) $\times$ Frequency, yielding values from 0 to 100. Because the PARS-3 total score is a formative composite index, computed by multiplying three distinct dimensions (intensity, duration, and frequency), rather than a reflective set of items intended to capture a single underlying latent construct, internal consistency indices such as Cronbach's alpha are not appropriate for this instrument [30]. We therefore assessed its reliability through test–retest stability. To examine the test-retest reliability of the scale, a subsample of 163 participants was selected to complete a repeated assessment at a two-week interval following the initial measurement. The test-retest reliability coefficient was 0.725.

All three variables were analyzed using their original total scores: physical exercise as the PARS-3 composite (range 0–100), and Social Media Addiction and psychological resilience as their respective scale totals (range 6–30). For all three, higher scores indicate higher levels of the construct. The PARS-3 and the Bergen Social Media Addiction Scale contain no reverse-keyed items; the Brief Resilience Scale includes three negatively worded items (items 2, 4, and 6), which were reverse-scored prior to computing the total, as specified by the original scale. Variables were not manually centered, because the random intercept in the RI-CLPM separates each person's stable level from their within-person deviations, so the autoregressive and cross-lagged paths are estimated on person-centered scores.

Data analysis

Initial descriptive and correlational analyses were conducted in SPSS 29. Intraclass correlation coefficients (ICCs) were calculated to assess stable between-person variance.

Two RI-CLPM Models were constructed using Mplus 8.3. The RI-CLPM represents an advanced extension of the traditional Cross-Lagged Panel Model (CLPM). The conventional CLPM fails to distinguish stable between-person differences from within-person fluctuations over time. The RI-CLPM incorporates random intercepts into the CLPM framework to represent each individual's long-term average level or stable trait on a given variable; consequently, the RI-CLPM demonstrates superior explanatory power compared to the CLPM [24]. The RI-CLPM was specified following the standard parameterization of Hamaker et al. [24]. For each of the three

variables, a random intercept was defined as a between-person latent factor with all factor loadings fixed to 1 across the three waves, capturing each individual's stable trait level. The observed scores at each wave were further decomposed into these random intercepts and a set of within-person latent factors, each defined by a single indicator with its loading fixed to 1; the residual variances of the observed indicators were fixed to zero, so that all observed variance was partitioned into between-person and within-person components. Autoregressive and cross-lagged paths were estimated exclusively among the within-person factors, and within-wave residual covariances among the within-person factors were freely estimated at each time point. The three random intercepts were allowed to covary to represent stable between-person associations. Gender and age were entered as time-invariant covariates predicting the observed scores, with their effects constrained to equality across the three waves [24]. We compared constrained models (with autoregressive and cross-lagged paths constrained to equality across time points) against unconstrained models (with freely estimated paths) to determine the optimal fitting model. The final models are presented in Figs. 1 and 2 (control variable paths are omitted from the figures).

All models were estimated using maximum likelihood estimation with robust standard errors (MLR), which is robust to non-normality; the path coefficients reported in Tables 2 and 3 were obtained from this estimation. Because the bootstrap procedure in Mplus is not available under MLR, the same models were re-estimated using maximum likelihood (ML) estimation to obtain bias-corrected bootstrap confidence intervals for the indirect effects, based on 10,000 bootstrap resamples. Point estimates were essentially identical across the two runs. The significance of each indirect effect was determined by whether its 95% bias-corrected bootstrap CI excluded zero. All models were estimated using full-information maximum likelihood (FIML), which uses all available data from the full sample of 632 participants under a missing-at-random assumption, thereby avoiding listwise deletion.

Results

Preliminary analyses

Descriptive statistics and intercorrelations are presented in Table S1 (Appendix). Physical exercise exhibited significant negative associations with Social Media Addiction ($r = -0.187$ to $-0.434, p < 0.01$) and positive associations with psychological resilience ($r = 0.118$ to $0.579, p < 0.01$) across all waves, whereas resilience was inversely related to Social Media Addiction ($r = -0.085$ to $-0.378, p < 0.05$). Intraclass correlation coefficients for physical exercise, resilience, and Social Media Addiction (0.364, 0.442, and

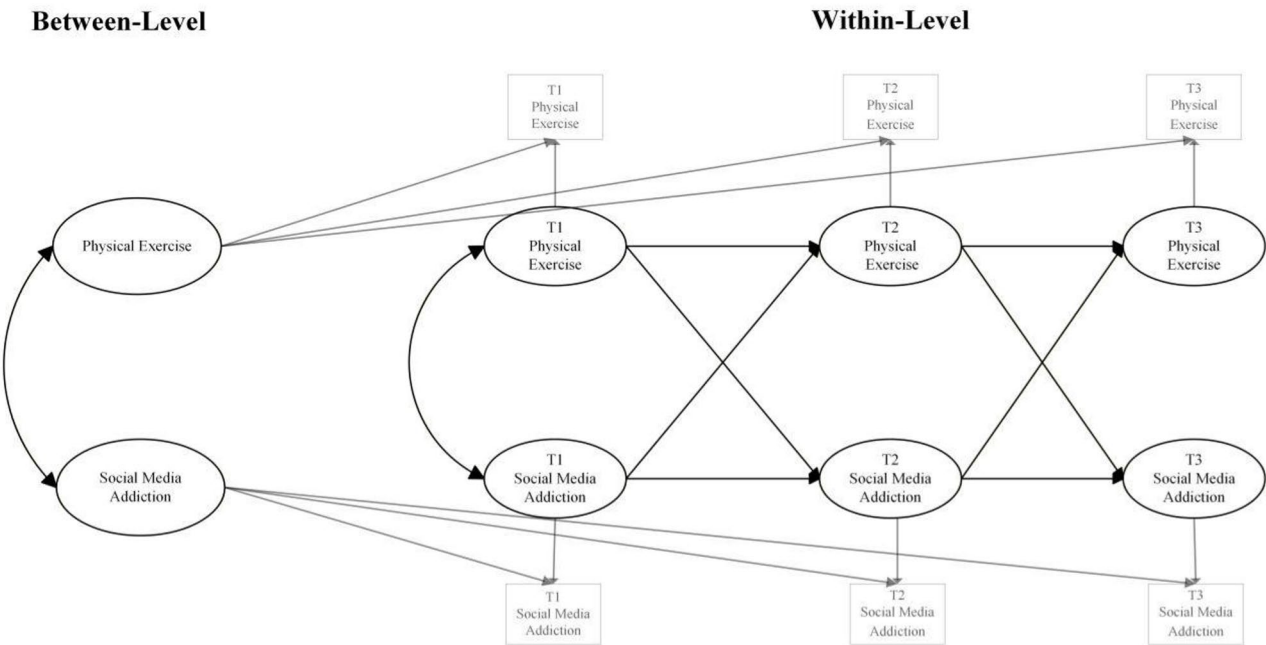


Fig. 1 RI-CLPM for Physical exercise and social media addiction (Model 1)

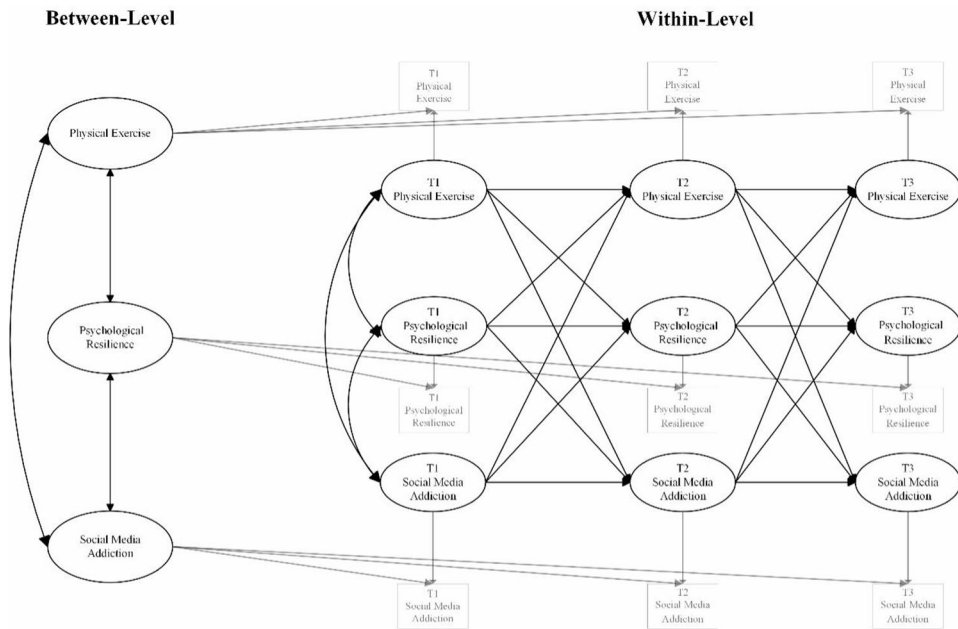


Fig. 2 RI-CLPM for Physical exercise, psychological resilience and social media addiction (Model 2)

0.524, respectively) indicated substantial between-person variance, justifying the application of RI-CLPM.

Table S2 presents the results of longitudinal measurement invariance testing. Following Chen’s [31] criteria ($\Delta CFI < 0.01$; $\Delta RMSEA < 0.015$), configural, metric, and scalar invariance were established for all variables, confirming structural consistency of measures across time points. To assess common-method bias, Harman’s single-factor test was conducted by entering all self-report

items into an unrotated exploratory factor analysis. The first factor accounted for 27.11% of the total variance, well below the 50% criterion, indicating that common-method variance was unlikely to substantially bias the results [32].

Model comparison and fit

Table 1 presents the model comparison and fit indices for the RI-CLPMs. To evaluate the temporal invariance

Table 1 Model comparison and fit for RI-CLPM

Models	CFI	SRMR	RMSEA [95% CI]	Δ CFI	Δ RMSEA
Model 1					
M1a	0.995	0.022	0.031 [0.000 0.059]	-	-
M1b	0.975	0.050	0.057 [0.038 0.077]	0.020	0.026
M1c	0.996	0.023	0.026 [0.000 0.053]	0.001	0.005
Model 2					
M2a	0.996	0.019	0.024 [0.000 0.050]	-	-
M2b	0.978	0.032	0.060 [0.044 0.078]	0.018	0.036
M2c	0.982	0.041	0.050 [0.033 0.066]	0.014	0.026

M1a / M2a = Fully unconstrained RI-CLPM; M1b / M2b = RI-CLPM with time invariance constraints on the autoregressive stabilities; M1c / M2c = RI-CLPM with time invariance constraints on the cross-lagged effects

RMSEA Root Mean Square Error of Approximation, CI Confidence Interval, SRMR Standardized Root Mean Square Residual

Table 2 RI-CLPM effects for physical exercise and social media addiction

	Path	β	SE	P
Cross-Lagged Effect	PET1 $\rightarrow$ SMA T2	-0.199	0.068	0.003
	PET2 $\rightarrow$ SMA T3	-0.138	0.054	0.011
	SMA T1 $\rightarrow$ PET 2	-0.146	0.067	0.029
	SMA T2 $\rightarrow$ PET 3	-0.242	0.073	0.001
Between-Person Effects Covariance	SMA — PE	-0.571	0.037	<0.001
Autoregressive Effects	PET 1 $\rightarrow$ PET 2	-0.559	0.077	<0.001
	PET 2 $\rightarrow$ PET 3	-0.637	0.064	<0.001
	SMA T1 $\rightarrow$ SMA T2	-0.135	0.094	0.150
	SMA T2 $\rightarrow$ SMA T3	0.210	0.06	<0.001
Within-Time Point Covariance	PET 1 — SMA T1	0.174	0.055	0.002
	PET 2 — SMA T2	-0.078	0.094	0.41
	PET 3 — SMA T3	0.027	0.066	0.679

All coefficients are fully standardized estimates

PE Physical Exercise, SMA Social Media Addiction

of the structural parameters, we compared the freely estimated RI-CLPM (M1a/M2a) against models imposing equality constraints on the autoregressive (M1b/M2b) and cross-lagged (M1c/M2c) paths, using Chen's [31] criteria (Δ CFI < 0.01, Δ RMSEA < 0.015) to judge whether a constraint produced a meaningful loss of fit. Constraining the autoregressive parameters substantially worsened fit in both models (M1b: Δ CFI = 0.020, Δ RMSEA = 0.026; M2b: Δ CFI = 0.018, Δ RMSEA = 0.036), indicating that the within-person carry-over parameters were not time-invariant. We therefore retained the freely estimated models as primary, which additionally allowed the cross-lagged parameters to differ across the two measurement intervals—theoretically warranted here because the intervals alternate between term time and the summer vacation, conditions under which exercise and social-media behaviours may plausibly differ. Constraining the cross-lagged paths left fit essentially unchanged for Model 1 (M1c: Δ CFI = 0.001, Δ RMSEA = 0.005) but produced a meaningful decrement for Model 2 (M2c:

Δ CFI = 0.014, Δ RMSEA = 0.026). Because the time-invariant cross-lag model fitted comparably in Model 1, we report it as a robustness check (Supplementary Material); the direction and significance of all focal paths were unchanged, confirming that the substantive conclusions do not depend on whether the cross-lagged paths are allowed to vary over time.

Between- and within-person associations between physical exercise and social media addiction

Path coefficients for Model M1a are presented in Table 2. At the between-person level, physical exercise was significantly negatively associated with Social Media Addiction ($\beta = -0.571$, $p < 0.001$). These results support Hypothesis 1. Within-person cross-lagged analyses revealed reciprocal relationships: physical exercise negatively predicted subsequent Social Media Addiction ($\beta = -0.199$ and -0.138 , $p < 0.05$), while Social Media Addiction likewise negatively predicted subsequent physical exercise ($\beta = -0.146$ and -0.242 , $p < 0.05$). These findings indicate that after controlling for stable between-person differences, increases in an individual's physical exercise predicted decreases in their Social Media Addiction, whereas increases in Social Media Addiction also suppressed subsequent physical exercise engagement. These bidirectional within-person effects support Hypothesis 2, including both the path from physical exercise to subsequent Social Media Addiction (H2a) and the reverse path (H2b).

The within-person autoregressive (carry-over) parameters also merit comment. The stabilities for physical exercise were sizable and negative (PE T1 $\rightarrow$ T2 $\beta = -0.559$; PE T2 $\rightarrow$ T3 $\beta = -0.637$; both $p < 0.001$), and the Social Media Addiction stability changed sign across waves (SMA T1 $\rightarrow$ T2 $\beta = -0.135$, $p = 0.150$; SMA T2 $\rightarrow$ T3 $\beta = +0.210$, $p < 0.001$). Because the random intercept removes stable trait variance, a negative autoregressive coefficient indicates that an above-average deviation at one wave tends to be followed by a below-average deviation at the next, that is, an oscillating rather than an inertial within-person process.

The mediating role of psychological resilience

Path coefficients for Model M2a are reported in Table 3. Physical exercise positively predicted subsequent psychological resilience (PE T1 $\rightarrow$ PR T2: $\beta = 0.400$, $p < 0.001$), which in turn negatively predicted later Social Media Addiction (PR T2 $\rightarrow$ SMA T3: $\beta = -0.287$, $p < 0.001$); these two paths constitute the longitudinal indirect effect reported in Table 4 (PE T1 $\rightarrow$ PR T2 $\rightarrow$ SMA T3), providing support for the mediating role of resilience. For the reverse direction, neither constituent path of the hypothesized mediation chain (SMA T1 $\rightarrow$ PR T2 $\rightarrow$ PE T3) was significant (SMA T1 $\rightarrow$ PR T2: $\beta = -0.084$, $p = 0.151$; PR

Table 3 RI-CLPM effects for physical exercise, social media addiction and psychological resilience

	Path	β	SE	P
Cross-Lagged Effect	PE T1 $\rightarrow$ SMA T2	-0.259	0.06	< 0.001
	PE T2 $\rightarrow$ SMA T3	-0.220	0.048	< 0.001
	SMA T1 $\rightarrow$ PET T2	-0.157	0.055	0.004
	SMA T2 $\rightarrow$ PET T3	-0.250	0.079	0.002
	PET T1 $\rightarrow$ PRT T2	0.400	0.057	< 0.001
	PET T2 $\rightarrow$ PRT T3	0.122	0.064	0.057
	SMA T1 $\rightarrow$ PRT T2	-0.084	0.059	0.151
	SMA T2 $\rightarrow$ PRT T3	0.033	0.05	0.514
	PRT T1 $\rightarrow$ PET T2	0.201	0.056	< 0.001
	PRT T2 $\rightarrow$ PET T3	0.101	0.105	0.336
	PRT T1 $\rightarrow$ SMA T2	-0.305	0.061	< 0.001
	PRT T2 $\rightarrow$ SMA T3	-0.287	0.067	< 0.001
Between-Person Effects Covariance	SMA — PE	-0.56	0.042	< 0.001
	SMA — PR	-0.301	0.086	< 0.001
	PE — PR	0.551	0.049	< 0.001
Autoregressive Effects	PET T1 $\rightarrow$ PET T2	-0.516	0.072	< 0.001
	PET T2 $\rightarrow$ PET T3	-0.612	0.065	< 0.001
	SMA T1 $\rightarrow$ SMA T2	-0.107	0.083	0.200
	SMA T2 $\rightarrow$ SMA T3	0.168	0.061	0.006
	PRT T1 $\rightarrow$ PRT T2	0.341	0.054	< 0.001
	PRT T2 $\rightarrow$ PRT T3	0.007	0.092	0.943
Within-Time Point Covariance	SMA T1 — PET T1	0.117	0.059	0.049
	SMA T1 — PRT T1	-0.234	0.068	0.001
	PET T1 — PRT T1	-0.044	0.063	0.492
	SMA T2 — PET T2	-0.061	0.084	0.469
	SMA T2 — PRT T2	-0.301	0.064	< 0.001
	PET T2 — PRT T2	-0.101	0.109	0.356
	SMA T3 — PET T3	0.000	0.069	0.999
	SMA T3 — PRT T3	-0.022	0.043	0.612
	PET T3 — PRT T3	-0.042	0.071	0.55

All coefficients are fully standardized estimates

PE Physical Exercise, PR Psychological Resilience, SMA Social Media Addiction

Table 4 Indirect paths between physical exercise, psychological resilience and social media addiction for the final RI-CLPM

Indirect Effects	RI-CLPM		Bootstrapped 95% CI	
	β	SE	Lower	Upper
PET1 $\rightarrow$ PRT2 $\rightarrow$ SMAT3	-0.115	0.036	-0.193	-0.051
SMAT1 $\rightarrow$ PRT2 $\rightarrow$ PET3	-0.009	0.014	-0.052	0.004

PE Physical Exercise, PR Psychological Resilience, SMA Social Media Addiction

T2 $\rightarrow$ PE T3: $\beta = 0.101$, $p = 0.336$), indicating that resilience did not mediate the effect of Social Media Addiction on subsequent physical exercise.

In addition, the within-person contemporaneous covariance between physical exercise and Social Media Addiction was positive and significant at T1 ($\beta = 0.174$, $p = 0.002$ in Model 1; $\beta = 0.117$, $p = 0.049$ in Model 2),

whereas the residual within-time covariances at T2 and T3 were non-significant.

Bootstrapping (10000 resamples) revealed a significant indirect pathway from physical exercise to Social Media Addiction via psychological resilience (PE T1 $\rightarrow$ PR T2 $\rightarrow$ SMA T3: $\beta = -0.115$, SE = 0.036, 95% CI [-0.193, -0.051]; Table 4). Because this bias-corrected confidence interval excluded zero, Hypothesis 3a was supported. In contrast, the reverse indirect pathway through which Social Media Addiction influenced physical exercise via psychological resilience was non-significant (SMA T1 $\rightarrow$ PR T2 $\rightarrow$ PE T3: $\beta = -0.009$, SE = 0.014, 95% CI [-0.052, 0.004]). As this confidence interval included zero, Hypothesis 3b was not supported. These results indicate that psychological resilience served as a mediator exclusively in the physical exercise $\rightarrow$ Social Media Addiction direction, demonstrating directional specificity of the mediation effect.

Auxiliary analyses: traditional CLPM

We also constructed two traditional CLPMs as auxiliary analyses (see Appendix). The results demonstrated that the CLPM findings were consistent with the RI-CLPM results: a significant negative reciprocal predictive relationship existed between Physical Exercise and Social Media Addiction; furthermore, Physical Exercise could indirectly influence Social Media Addiction through Psychological Resilience, whereas the reverse mediation pathway was not significant.

Discussion

Using three-wave longitudinal data from university students, this study applied a Random Intercept Cross-Lagged Panel Model to decompose within- and between-person associations among physical exercise, psychological resilience, and Social Media Addiction. The findings revealed that at the within-person level, physical exercise and Social Media Addiction exhibited a reciprocal dynamic relationship, and physical exercise indirectly reduced Social Media Addiction through enhancing psychological resilience. Unlike the cross-sectional approach commonly used in prior studies [8, 33], this study employed a multilevel longitudinal design that goes beyond documenting the between-person association whereby students who exercise more report less addiction. After controlling for between-person differences, it further showed that an increase in a student's own level of exercise predicts a subsequent decline in that same student's Social Media Addiction, something that cross-sectional and traditional cross-lagged models cannot identify.

Physical exercise and social media addiction

At the between-person level, physical exercise was significantly and negatively associated with Social Media Addiction, indicating that students with habitually higher physical exercise levels tend to report lower Social Media Addiction. This aligns with prior cross-sectional evidence linking physical exercise to reduced Social Media Addiction [33, 34].

The current study identified a bidirectional dynamic association between physical exercise and Social Media Addiction at the within-person level. On the one hand, increases in physical exercise at a given time point predicted decreases in Social Media Addiction at subsequent time points. From a behavioral-contextual perspective, the temporal and social contexts in which exercise occurs (e.g., athletic training, physical education classes, or outdoor recreational activities) naturally redirect university students' attention away from digital devices, thereby disrupting habitual social media checking behaviors [10, 35]. On the other hand, increases in Social Media Addiction at a given time point likewise predicted decreases in physical exercise at subsequent time points. This finding corroborates prior evidence that problematic social media use compromises students' motivation and capacity for health-promoting behaviors [36, 37]. Social Media Addiction is characterized by attentional capture and compulsive checking, which deplete discretionary time and cognitive resources [38]. Moreover, excessive use (particularly at bedtime) has been linked to poor sleep quality, daytime fatigue, and diminished energy [39], collectively undermining the motivation and physical readiness necessary for exercise engagement.

Beyond the cross-lagged effects, the within-person autoregressive parameters also merit attention. The autoregressive coefficient for physical exercise was negative, indicating that, at the within-person level, states deviating from one's habitual exercise level did not persist but instead tended to fall back or even reverse at the following wave, that is, a negative carry-over effect. This reversal may be linked to the measurement rhythm of the present study. The three waves were spaced approximately six months apart, alternating between term/examination periods (T1, T3) and the summer vacation (T2), and prior research suggests that these two types of periods differ in the behaviors of interest here. During term time, students' daily routines are constrained by class schedules, the accessibility of sports facilities, and academic workload, and the structure of academic life is itself associated with the diurnal distribution of physical exercise [40]. During vacations, external constraints loosen and daily rhythms become less structured, physical exercise levels decline accordingly [41], and both physical exercise and social media use are reorganized around family and leisure settings.

These observations point to a limitation of our design and a direction for future work. Because waves and seasonal contexts were confounded, we cannot fully separate the negative autocorrelation from this alternation. Future studies should break this correspondence, for example by adding waves or scheduling all assessments within the academic term, and should include within-term contextual variation, such as actual workload and the settings in which activity takes place, as time-varying covariates. Such designs would clarify the extent to which this negative autocorrelation can be accounted for by contextual structure.

At T1, we observed a positive within-person concurrent covariance between physical exercise and Social Media Addiction, indicating that at the baseline measurement, students whose exercise levels were above their own typical level also tended to be above their own typical level in Social Media Addiction. Interpreting this concurrent association requires distinguishing three types of parameters that differ in nature within the model: the random-intercept covariance captures stable, trait-level differences; the cross-lagged paths capture prospective within-person prediction; and the concurrent covariance captures co-occurring fluctuations at the same time point. Because these estimates operate at different analytical levels and reflect associations of different kinds, they can diverge in direction [24, 42]. One plausible explanation is a shared time-varying opportunity factor: during periods when discretionary time is more plentiful, students may engage in both more exercise and more social media use, since both are leisure behaviors that expand along with available time [43]. Because this positive association occurs within a single time point and is nondirectional, whereas across time an increase in one behavior prospectively crowds out the other (that is, the cross-lagged paths are negative), it does not alter the negative relationships revealed in this study at the level of long-term stable (between-person) differences and at the level of cross-temporal prediction.

These findings provide a foundation for developing integrated intervention strategies. First, given the negative between-person correlation, helping university students develop regular exercise habits may be valuable for reducing Social Media Addiction risk. Universities should incorporate the promotion of physical exercise into the broader framework of student mental health enhancement, creating conditions and environments that facilitate sustained exercise participation and fostering the development of regular exercise habits among students.

Second, the reciprocal relationship between physical exercise and Social Media Addiction at the within-person level indicates that escalations in Social Media Addiction lead to declines in physical exercise, while reductions

in physical exercise may in turn further reinforce Social Media Addiction, rendering the two susceptible to forming a vicious cycle. Therefore, intervention program design should incorporate a dual approach of “breaking the vicious cycle” and “initiating a virtuous cycle.” On the one hand, psychological counselors and student advisors should simultaneously attend to and promote the restoration and maintenance of students’ physical exercise behaviors when helping them address excessive social media use; on the other hand, physical education instructors and exercise specialists should also monitor changes in students’ digital media usage patterns, treating these as early warning signals of declining exercise motivation. This approach would establish a collaborative, multi-stakeholder comprehensive intervention system that promotes the coordinated development of university students’ physical and mental health.

The mediating role of psychological resilience

At the within-person level, psychological resilience emerged as a significant mediator linking physical exercise to Social Media Addiction, corroborating prior evidence that resilience constitutes a critical psychological mechanism underlying the mental health benefits of exercise [7]. Research by Lin et al. [44] similarly found that psychological resilience is considered a protective factor against Social Media Addiction, with adolescents possessing higher levels of resilience demonstrating adaptive coping responses to difficult life events, thereby reducing tendencies toward addictive social media use. Mechanistically, the process through which physical exercise reduces Social Media Addiction via enhanced psychological resilience can be understood from multiple perspectives. At the physiological level, the physiological toughening model [45] proposes that physical exercise, as an intermittent physical stressor, may promote cross-adaptation to other types of stressors. According to this account, regular physical exercise has been linked to a characteristic pattern of physiological changes, including an initial elevation in catecholamine responses followed by rapid recovery, together with attenuated hypothalamic-pituitary-adrenal axis reactivity [46]. Such neuro-endocrine adaptation is thought to support greater stress tolerance and may strengthen the physiological foundation of psychological resilience [47]. At the emotion regulation process level, the Affect-Regulation Framework proposed by Troy et al. [48] indicates that flexible deployment of affect regulation strategies constitutes a key process mechanism for achieving psychological resilience. Physical exercise, as an activity conducive to enhancing affect regulation capacity [49], may elevate resilience levels by strengthening individuals’ affect regulation flexibility, thereby reducing their tendency to engage in compensatory social media use in response to emotional

dysregulation. From a developmental psychology perspective, the present finding corroborates the adolescent resilience theory proposed by Zimmerman et al. [50], which holds that promotive factors can break the chain connecting risk exposure to negative outcomes. Psychological resilience reduces negative outcomes by interrupting the influence of risk factors; individuals with high psychological resilience can more effectively mobilize internal resources to cope with stress rather than relying on external compensatory means such as social media. This finding provides longitudinal empirical evidence for a deeper understanding of the mechanisms through which adolescent psychological resilience functions as a protective factor [51], further enriching the theoretical understanding of resilience protection mechanisms [52].

Additionally, psychological resilience did not significantly mediate the within-person effect of Social Media Addiction on subsequent physical exercise. A possible explanation is that the erosion of psychological resilience by Social Media Addiction may be a slow and cumulative process [53], implying that the temporal span required for the entire causal chain may exceed the intervals between adjacent measurement time points, rendering this mediating effect difficult to detect at the within-person level. Future research could employ varying interval lengths to further examine whether this reverse pathway holds over longer time scales.

At the practical level, this mediating effect suggests that the key to physical exercise alleviating addictive behaviors lies in cultivating individuals’ internal psychological resources. Accordingly, the design of university physical education curricula should not merely focus on achieving targets for exercise volume and intensity but should also emphasize the cultivation of psychological resilience components—for example, through setting moderately challenging tasks and organizing team sports to help students temper their willpower, enhance their sense of social connectedness, and experience a sense of accomplishment from overcoming difficulties during exercise. Moreover, university counseling centers could design integrated interventions combining physical exercise with resilience training to promote physical health, build resilience, and prevent behavioral addiction.

Limitations and future research

Despite methodological and theoretical contributions, this study has several limitations. First, participants were recruited exclusively from two universities in China, potentially limiting cross-cultural generalizability. Students from different cultural contexts may vary in social media usage patterns, physical exercise norms, and the development of psychological resilience. Replication across geographically and culturally diverse samples is warranted to ascertain the cross-cultural generalizability

of the present results. Second, the physical exercise measurement instrument employed in this study assessed only overall activity levels without differentiating among various types of physical activities. Different exercise modalities vary in terms of social interactivity and emotion regulation effects, potentially exerting differential influences on psychological resilience and Social Media Addiction. Future research could refine the classification of exercise types to investigate which forms of physical exercise are most effective for preventing Social Media Addiction. Third, as noted earlier, the six-month interval placed T1 and T3 within school terms but T2 during the summer break. Because exercise and social media use may differ between term time and vacation, this structure could have driven the oscillation in the within-person autoregressive parameters while also shaping the cross-lagged estimates. The study therefore cannot formally disentangle seasonal effects from temporal ones. Future research should adopt measurement schedules that are not collinear with the academic calendar, for instance by spacing equally timed waves within a single term, or by shortening the interval so that term and vacation phases are each sampled repeatedly, thereby separating seasonal from temporal dynamics. Fourth, although the present study revealed several meaningful findings, it did not collect a number of background variables that may be associated with both physical exercise and social media use, such as participants' academic major, urban versus rural background, and their pre-existing regular exercise habits, and the potential confounding influence of these factors could therefore not be examined directly. Future research should explicitly measure these characteristics and, where appropriate, incorporate them as covariates, so as to further clarify the within-person dynamics among physical exercise, psychological resilience, and Social Media Addiction. Finally, although the study design mitigated common method bias to some extent, all three constructs were assessed through self-reports from the same source, so some degree of common method bias may remain. Self-report measures are also susceptible to social desirability and response styles. Future research would benefit from incorporating multi-source or objective measures (for example, accelerometer-based activity data and platform-logged usage time) to further reduce reliance on assessment by a single method.

Conclusion

Based on one-year longitudinal data comprising three measurement waves from university students, the current study adopted a RI-CLPM framework to distinguish stable between-person variance from temporal within-person dynamics across physical exercise, psychological resilience, and Social Media Addiction. Two key findings emerged: first, students with habitually higher physical

exercise levels reported lower Social Media Addiction at the between-person level; second, physical exercise and Social Media Addiction demonstrated reciprocal within-person effects over time. Additionally, psychological resilience served as a mediating mechanism through which physical exercise conferred protective effects against addiction. These results provide an evidence base for university mental health programs that leverage exercise interventions to cultivate resilience and reduce Social Media Addiction risk.

Supplementary Information

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Supplementary Material 1.

Authors' contributions

Y.F. conceptualized the study, performed data analysis, and wrote the main manuscript text. J.W. contributed to data collection and prepared Figs. 1 and 2. R.L. contributed to data collection and literature review. C.L. assisted with data curation and methodology. J.S. supervised the project, contributed to study design, and revised the manuscript. All authors reviewed and approved the final manuscript.

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Data availability

The datasets used and analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

This study was conducted in accordance with the Declaration of Helsinki and was approved by the Ethics Committee of Xihua University (Approval No.: XH250124-01). Written informed consent was obtained from all individual participants included in the study prior to data collection. Participants were informed of the study's objectives and procedures, and were assured of data confidentiality and anonymity.

Consent for publication

All participants provided consent for the publication of anonymised data.

Competing interests

The authors declare no competing interest.

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