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ORIGINAL CONTRIBUTION

Longitudinal associations between problematic Internet use, self-esteem, and depressive symptoms among Chinese adolescents

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Abstract

Problematic Internet use (PIU) has a negative impact on self-esteem among adolescents, thereby making them be vulnerable to developing depressive symptoms. However, there is a lack of longitudinal studies focusing on the process. This study aimed to explore the longitudinal associations between PIU, self-esteem, and depressive symptoms. A total of 1,736 adolescents completed this longitudinal study. The baseline survey was conducted in 2019, and the follow-up surveys were performed at 1-year and 2-year later. PIU, self-esteem, and depressive symptoms were measured. A cascade model was used to examine the longitudinal associations between PIU, self-esteem, and depressive symptoms. The mean age of participants was 13.6 (1.5) years at baseline. The final results observed significant within-time associations between PIU, self-esteem, and depressive symptoms at each time point. PIU and low level of self-esteem could predict subsequent depressive symptoms among adolescents, and depressive symptoms were also associated with subsequent PIU and self-esteem. Both PIU and self-esteem show bidirectional predictions with depressive symptoms among Chinese adolescents. Schools and parents should give more attention to adolescents prone to developing depressive symptoms and more social support to reduce their negative emotions. Health-related professionals should incorporate practical knowledge and skills into the education of adolescents to help them better control Internet use, attenuating the risk of future depressive symptoms.

Keywords Problematic Internet use · Self-esteem · Depressive symptoms · Adolescent

Introduction

Depressive symptoms are a serious mental health problem among adolescents worldwide [1, 2]. Adolescents are in a critical period of transition from childhood to adulthood, during which significant emotional, social, and behavioral changes occur, and adolescents are more vulnerable to negative emotions [3, 4]. Adolescents with depressive symptoms are prone to developing depressive disorders in adulthood, and are associated with a range of adverse consequences, such as substance abuse, social problems, and suicidal behavior, causing a tremendous burden on individuals, families, and society [5, 6]. Prior evidence suggested that about 11–20% of adolescents in western countries suffered from depressive symptoms [7, 8], while the prevalence among Chinese adolescents was approximately 20% [9]. Therefore, it is necessary to enhance the early intervention for adolescents with depressive symptoms. Compelling studies have demonstrated that behavioral problem in adolescents, especially problematic Internet use (PIU), is associated with a higher risk of depressive symptoms [10, 11].

PIU, also known as Internet addiction disorder, is characterized by excessive use of the Internet or unable to control the desire to surf the Internet well [12, 13], which negatively impacts many aspects of life. PIU could be related to different types of excessive use of internet activities, such as internet gaming, social networking. Compared to adults, if adolescents spend more time on the Internet, they would be more susceptible to PIU [10]. Previous studies have reported that about 10% of adolescents might be addicted to the Internet in other countries [12], and 17.2% of Chinese adolescents had problems in controlling Internet use [14]. PIU not only disrupts an individual's school and social activities, but it can also cause several adverse outcomes in terms of mental health [13, 15, 16]. A growing body of literature has shown that PIU and excessive use of gaming were associated

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with depressive symptoms among adolescents [12, 14, 17]. Adolescents with Internet addiction problems, especially problematic gaming, tended to indulge in the virtual world, reducing real-life activities and contact with others [12, 18, 19], inevitably leading to increased reliance on the Internet, impaired critical interpersonal relationships, and reduced social support, resulting in feelings of isolation and depression [14]. Besides, evidence has indicated that depressive symptoms were associated with various behavioral problems, including PIU [2].

Additionally, extensive research suggested that self-esteem may indirectly play an important role in the association between PIU and depressive symptoms [11, 15]. Specific forms of inappropriate Internet use, such as the use of social networking sites, tended to elicit upward social comparison with others who had perfect bodies and lives, leading to a decrease in adolescents' satisfaction with their own lives [20]. Excessive Internet use could lead to a diminished sense of self-control, resulting in a lower level of self-esteem [15], and a state of low self-esteem may make it difficult to regulate their emotions, making them more likely to develop depressive symptoms subsequently [11]. The vulnerability model proposes that low self-esteem is an antecedent of depressive symptoms and that if a person develops a negative self-concept, the vulnerability is triggered when he encounters negative life events, causing negative emotions not to be relieved in time, which makes him more likely to develop depressive symptoms [21]. However, the scar model suggests that low self-esteem is a consequence of depressive symptoms and that depressive symptoms erode an individual's self-concept, leading to a lower level of self-esteem [22]. Based on previous evidence [11, 15, 18, 23], we found complex associations among PIU, self-esteem and depressive symptoms, and fewer studies have focused on this process. In a Chinese cross-sectional study, Zhang et al. found differences in the predictive effect of social networking site use on depressive symptoms among adolescents with different levels of self-esteem [24]. To our knowledge, there is a lack of longitudinal studies focusing on the process. Therefore, it is significant to conduct longitudinal studies to fill this gap. We hypothesized that self-esteem might play an important role in the association between PIU and depressive symptoms. The developmental cascade model is a robust statistical modeling approach designed to explore direct or indirect associations between multiple variables across time by controlling for cross-sectional associations between domains, as well as stability effects within domains [25]. It is widely used in previous studies by many researchers to explore the longitudinal association between externalizing and internalizing problems in children and adolescents [26, 27].

The purpose of this study was to clarify the longitudinal associations between PIU, self-esteem, and depressive symptom among Chinese adolescents by using a developmental cascade model, providing a theoretical basis for promoting the mental health development of adolescents.

Methods

Study design and participants

Data were drawn from the Longitudinal Study of Adolescents' Mental and Behavioral Well-being Research in Guangzhou, China [28] (Registration No. ChiCTR1900022032). In the longitudinal study, ten public high schools from four central urban districts of Guangzhou were chosen via cluster sampling method, and students in grade one within the selected schools were invited to participate voluntarily. Data were collected at baseline in January 2019, and the follow-up was conducted one year and two years after the baseline survey. A total of 1976 participants were invited at baseline, and 1957 students were present and completed the survey (response rate: 99.0%). Of the recruited students, 1738 students provided eligible data after two follow-up surveys (retention rate: 88.8%) and were analyzed in this study. In each survey, students completed a standardized self-reported questionnaire in the classroom during a regular class period (45 min) without the presence of teachers (to avoid any potential information bias). The investigation and data analysis were anonymous and de-identified.

After the intention and procedure of this study had been fully explained in detail, written informed consent was obtained from each participating student and one of their parents or legal guardians. The research was conducted in accordance with the Declaration of Helsinki and obtained ethical approval from Sun Yat-sen University, School of Public Health Institutional Review Board (Ethics Number: L2017060).

Measures

Problematic internet use

The Young's Internet Addiction Test (IAT) is a 20-item self-report scale used to assess PIU [29]. The Chinese version of IAT has been validated and widely used in the Chinese population [30]. The respondents were asked to rate the frequency on a 5-point scale ranging from "not at all" (= 1) to "always" (= 5), with a total score from 20 to 100. In the current study, respondents with higher scores suggested that they had a higher level of PIU. The Cronbach's alpha values for this scale at each time point were 0.900, 0.907, and 0.924, respectively.

Self-esteem

The Chinese version of the Rosenberg Self-Esteem Scale (RSES) is a 10-item self-report scale used to assess self-esteem, with questions focusing on an individual's general feelings about self-worth and self-acceptance [31]. Respondents were asked to rate their feelings on a 4-point scale (from 1 = "strongly disagree" to 4 = "strongly agree"), with a total score between 10 and 40. The Chinese version has been validated and has shown good reliability in studies of Chinese adolescents [32]. In this study, we utilized scores to reflect the participants' self-esteem, with higher scores indicating higher levels of self-esteem. The Cronbach's alpha values for this scale at each time point were 0.851, 0.865, and 0.883, respectively.

Depressive symptoms

The Center for Epidemiologic Studies Depression Scale (CES-D) is a 20-item self-report scale designed to measure depressive symptoms [33]. The Chinese version of this scale has been validated in Chinses adolescents [34]. The participants were asked to rate the frequency of 20 symptoms of depression on a 4-point scale (from 0 = "rarely or none of the time" to 3 = "most or all of the time"), with a maximum score of 60. In this research, participants who got higher scores of the CES-D indicated that they suffered a higher level of depressive symptoms. The Cronbach's alpha values for this scale at each time point were 0.886, 0.900, and 0.902, respectively.

Covariates

The covariates included age, sex (1 = boy, 2 = girl), living arrangement, household socioeconomic status (HSS), academic pressure, classmate relationships, teacher-classmate relationships, and current alcohol consumption. Living arrangement was assessed according to the answer about whom they lived with (1 = living with parents, 2 = living with a single parent, and 3 = living with others) [35]. HSS was measured by their perception of family socioeconomic status (1 = good, 2 = average, 3 = poor). Academic pressure was measured by asking the adolescents' perception of the pressure by themselves (1 = none, 2 = moderate, 3 = severe) [36]. Relationships with classmates and teachers were measured based on their perception of the relationships (1 = good, 2 = average, and 3 = poor). Current alcohol consumption was measured by asking the students how many days they drank alcohol during the last 30 days, and those who answered one or more days were identified as current drinking [37].

Statistical analysis

First, descriptive analyses were conducted to describe the sample characteristics, and the data were expressed as mean (standard deviation, SD) and number (%). Second, preliminary analyses were performed to compare the difference in demographic characteristics between the analytic sample and those who dropped out by using a Chi-square test (for categorical variables) or a *t* test (for continuous variables). Third, correlation analyses were used to examine the association between PIU, self-esteem, and depressive symptoms at three-time points (baseline to 2-year follow-up). Fourth, a cascade model was used to explore the longitudinal association between PIU, self-esteem, and depressive symptoms. The development cascade model requires repeated assessments of all domains over time and controls for stability and covariance across domains. When stability and covariance are considered, developmental cascade effects reflect direct (unidirectional or directional) and/or indirect (through various pathways) associations among multiple domains.

In the current study, a total of six models were examined. Model 1 is an autoregressive model where the autoregressive path reflects the stability and continuity among PIU, self-esteem, and depressive symptoms. Model 2 retained the autoregressive path, and the within-time correlations of the three variables measured within the same wave were also considered. In Model 3, all paths in Model 2 were retained, and cross-lag paths were also incorporated, with significant cross-lag paths suggesting directional effects between different variables beyond the stable paths from the previous time to the next. Subsequently, we tested whether all paths in Model 3 were sex invariant. In Model 4, a multigroup model was established where all paths were free to be estimated across sex groups, while all paths remained equal across sex groups in Model 5. A Wald chi-square test was used to identify whether there were any significant sex differences in any path. In Model 6, we adjusted for covariates and observed whether the paths in Model 3 remained significant.

All models were examined using path analysis (all variables are observed variables) with maximum likelihood robust (MLR) estimation in Mplus 8.3 (Muthén & Muthén, Los Angeles, CA). MLR was used to account for potential issues of non-normal distributions because it could produce robust standard errors. Model fit was evaluated by a variety of fit indices, consisting of the comparative fit index (CFI > 0.90 indicates acceptable fit), the Tucker–Lewis Index (TLI > 0.90 indicating acceptable fit), the root mean square error of approximation (RMSEA < 0.08 indicates acceptable fit), the standardized root mean square residual (SRMR < 0.08 indicates good fit), and the Akaike information criterion (AIC) and the Bayesian information criterion (BIC, a lower AIC/ BIC indicated a better model fit) [38, 39]. Full information

maximum likelihood estimation was used to handle the missing data [26, 27]. The Satorra–Bentler scaled chi-square difference test was performed to compare nested models and to identify the most optimal model due to the use of MLR estimation.

All data analyses were performed using R 3.6.1 (the R Foundation for Statistical Computing, Vienna, Austria) and Mplus 8.3 (Muthén & Muthén, Los Angeles, CA), and all statistical tests were two-sided, with a *P* less than 0.05 considered statistically significant.

Result

Sample characteristic

The baseline sample characteristic was presented in Table 1. At baseline, the mean (SD) age of the students was 13.6 (1.5) years, and half of them (875/1738) were male; 1422 (81.8%) lived with their parents, 893 (51.4%) reported good HSS, and 1512 (87.0%) responded they did not drink during the last 30 days. Besides, most students had average academic pressure (46.6%, 810/1738), and reported a good relationship with their classmates (85.6%, 1488/1738) and teachers

Table 1 Baseline sample characteristics between follow-up and loss-to-follow-up participants

Variable	Total ($n=1957$)	Follow-up ($n=1738$)	Loss-to-follow-up ($n=219$)	P^*
Age, mean (SD), year	13.6 (1.5)	13.6 (1.5)	13.5 (1.4)	0.922
Gender				0.297
Male	994 (50.8)	875 (50.3)	119 (54.3)	
Female	963 (49.2)	863 (49.7)	100 (45.7)	
Living arrangement				0.066
Living with parents	1594 (81.5)	1422 (81.8)	172 (78.5)	
Living with a single parent	192 (9.8)	161 (9.3)	31 (14.2)	
Living with others	167 (8.5)	151 (8.7)	16 (7.3)	
Missing data	4 (0.2)	4 (0.2)	0 (0)	
HSS				0.127
Good	1012 (51.7)	893 (51.4)	119 (54.3)	
Average	862 (44.0)	776 (44.6)	86 (39.3)	
Poor	77 (3.9)	64 (3.7)	13 (5.9)	
Missing data	6 (0.3)	5 (0.3)	1 (0.5)	
Academic pressure				0.614
None	516 (26.4)	463 (26.6)	53 (24.2)	
Moderate	910 (46.5)	810 (46.6)	100 (45.7)	
Severe	526 (26.9)	462 (26.6)	64 (29.2)	
Missing data	5 (0.3)	3 (0.2)	2 (0.9)	
Classmate relationship				**0.033**
Good	1663 (85.0)	1488 (85.6)	175 (79.9)	
Average	254 (13.0)	220 (12.7)	34 (15.5)	
Poor	34 (1.7)	26 (1.5)	8 (3.7)	
Missing data	6 (0.3)	4 (0.2)	2 (0.9)	
Teacher-classmate relationship				**0.006**
Good	1605 (82.0)	1438 (82.7)	167 (76.3)	
Average	307 (15.7)	262 (15.1)	45 (20.5)	
Poor	27 (1.4)	20 (1.2)	7 (3.2)	
Missing data	18 (0.9)	18 (1.0)	0 (0)	
Current drinking				0.156
No	1694 (86.6)	1512 (87.0)	182 (83.1)	
Yes	242 (12.4)	208 (12.0)	34 (15.5)	
Missing data	21 (1.1)	18 (1.0)	3 (1.4)	

HSS household socioeconomic status, *SD* standard deviation

*The *t* test was used for age data, and the chi-square test was used for categorical variables

(82.7%, 1438/1738). There were no significant differences in most demographic variables (age, sex, living arrangement, HSS) between the analytic sample and those who dropped out of the study. The mean (SD) scores of IAT, SES and CES-D for participants from baseline to 2-year follow-up were shown in Table 2. At each time point, boys had a higher level of self-esteem ($P < 0.05$), while girls reported more severe depressive symptoms ($P < 0.05$). There was no significant difference in terms of PIU.

Correlation among PIU, self-esteem, and depressive symptoms

Within-time and across-time correlations among PIU, self-esteem, and depressive symptoms were presented in Table 3. All variables showed considerable stability over three years. Besides, at each time point, PIU was negatively associated with self-esteem and positively associated with depressive symptoms, and self-esteem was negatively associated with depressive symptoms (all $P < 0.05$).

Longitudinal association between PIU, self-esteem, and depressive symptoms

A cascade model was used to explore the longitudinal association between PIU, self-esteem, and depressive symptoms. Model fit indices and nested model comparisons were presented in Table 4. Model 1 has an acceptable fit to the data (CFI = 0.879, RMSEA = 0.104, 90% CI 0.095–0.112, SRMR = 0.105), model 2 also has a good fit (CFI = 0.960, RMSEA = 0.064, 90% CI 0.055–0.073, SRMR = 0.060), and is better than model 1 ($\Delta\chi^2 = 240.903$, $P < 0.001$). Model 3 also showed a good fit (CFI = 0.983, RMSEA = 0.063, 90% CI 0.050–0.078, SRMR = 0.023), and fit the data better

Table 2 The scores of problematic Internet use, self-esteem, and depressive symptoms in the longitudinal study

Time point	Total		Male		Female		*P*
	N	Mean (SD)	*N*	Mean (SD)	*N*	Mean (SD)	
Problematic internet use							
t1	1735	36.3 (12.6)	872	36.1 (12.7)	863	36.5 (12.6)	0.464
t2	1729	36.2 (12.8)	870	35.8 (13.0)	859	36.6 (12.4)	0.165
t3	1702	35.9 (13.4)	856	35.5 (13.3)	846	36.3 (13.5)	0.243
Self-esteem							
t1	1734	30.7 (5.2)	872	31.1 (5.0)	862	30.2 (5.3)	**< 0.001**
t2	1732	30.8 (5.4)	871	31.2 (5.5)	861	30.3 (5.3)	**< 0.001**
t3	1698	30.8 (5.6)	852	31.1 (5.6)	846	30.5 (5.6)	**0.038**
Depressive symptom							
t1	1730	13.3 (9.9)	872	12.0 (8.9)	858	14.6 (10.6)	**< 0.001**
t2	1734	13.6 (10.4)	872	12.1 (9.9)	862	15.1 (10.6)	**< 0.001**
t3	1728	13.4 (10.2)	870	12.0 (9.3)	858	14.9 (10.8)	**< 0.001**

t1, t2, and t3 represented the assessment in baseline, 1-year follow-up and 2-year follow-up, respectively

Table 3 Correlations between PIU, self-esteem and depressive symptom

Variables	1	2	3	4	5	6	7	8	9
Problematic internet use									
1. t1	1								
2. t2	0.648	1							
3. t3	0.557	0.670	1						
Self-esteem									
4. t1	− 0.280	− 0.211	− 0.155	1					
5. t2	− 0.202	− 0.267	− 0.193	0.615	1				
6. t3	− 0.152	− 0.225	− 0.280	0.514	0.628	1			
Depressive symptom									
7. t1	0.401	0.286	0.230	− 0.634	− 0.482	− 0.403	1		
8. t2	0.318	0.399	0.315	− 0.469	− 0.615	− 0.486	0.640	1	
9. t3	0.278	0.313	0.422	− 0.401	− 0.470	− 0.643	0.521	0.654	1

t1, t2, and t3 represented the assessment in baseline, 1-year follow-up and 2-year follow-up, respectively. All correlation coefficients are significant at $P < 0.001$

Table 4 Model fit statistics and nested model comparisons

Model	Model fit statistics									Difference tests of relative fit				
	df	*c*	χ^2	CFI	TLI	RMSEA	SRMR	AIC	BIC	Model comparison	*cd*	$\Delta\chi^2$	Δdf	*P*
1. Autoregressive	24	1.38	438.348	0.879	0.834	0.104	0.105	66,566.04	66,679.08					
2. Autoregressive and within-time correlation	21	1.35	158.038	0.96	0.937	0.064	0.06	99,617.09	99,794.72	1 vs 2	1.63	3	240.903	**< 0.001**
3. Autoregressive, within-time correlation and cross-lags	9	1.37	67.284	0.983	0.983	0.063	0.023	99,519.99	99,762.21	2 vs 3	1.33	12	90.765	**< 0.001**
Gender difference														
4. Unconstrained model	18	1.40	66.074	0.989	0.915	0.058	0.012	119,521.06	120,877.51					
5. Constrained	45	1.40	112.170	0.984	0.952	0.043	0.024	119,531.30	120,742.41	4 vs 5	1.40	27	46.012	**< 0.001**
Adjusting for covariates														
6. Autoregressive, within-time correlation and cross-lags	9	1.40	59.209	0.988	0.896	0.059	0.011	122,038.89	122,808.62					

The Satorra–Bentler scaled chi-square difference test was used to compare nested models

c scaling correction factor for MLR, *CFI* comparative fit index, *TLI* Tucker–Lewis Index, *RMSEA* root mean square error of approximation, *SRMR* standardized root mean square residual, *AIC* Akaike information criterion, *BIC* Bayesian information criterion, *cd* difference for scaling correction factor

than model 2 ($\Delta\chi^2 = 90.765$, $P < 0.001$). In model 3, without adjusting for covariates, all variables exhibited good temporal stability. In addition, the within-time associations between PIU, self-esteem and depressive symptoms were significant. As for the cross-lag effects, significant links from PIU and self-esteem at each time point to depressive symptoms were found at the next time point. Besides, depressive symptoms in baseline were negatively associated with self-esteem in 1-year follow-up. Self-esteem and depressive symptoms in 1-year follow-up could predict PIU in 2-year follow-up. The significant paths and standardized estimates in model 3 were represented in Figure S1.

Sex differences in all paths were also examined. The unconstrained model (model 4) showed a good fit (CFI = 0.983, RMSEA = 0.065, 90% CI 0.051–0.080, SRMR = 0.023), as did the constrained model (model 5) (CFI = 0.975, RMSEA = 0.050, 90% CI 0.041–0.060, SRMR = 0.041). The unconstrained model showed a better fit than the constrained model ($\Delta\chi^2 = 58.889$, $P < 0.001$), indicating that there were sex differences in the paths in the model. Wald chi-square tests found that the within-time association of self-esteem with depressive symptoms (baseline) was stronger in females, and temporal stability (from 1-year follow-up to 2-year follow-up) of PIU and depressive symptoms was stronger in females. However, there was no significant sex difference in the cross-lag paths.

In model 6, after adjusting for living arrangement, HSS, academic pressure, classmate relationships, teacher-classmate relationships, and current alcohol consumption, the estimates of most paths in model 3 were attenuated (Table 5), and all significant paths in model 3 remained statistically significant, except that self-esteem in 1-year follow up was not associated with PIU in 2-year follow up. The significant paths and standardized estimates in model 6 are represented in Fig. 1.

Discussion

To our knowledge, this is the first study to test the longitudinal association between PIU, self-esteem, and depressive symptom through a cascade model in a large-scale adolescent sample. Our final model found that after adjusting for the covariates, PIU, self-esteem, and depressive symptoms were associated with each other at each time point, and the stability paths for all variables were significant. In addition, both PIU and self-esteem had significant cross-lag effects on depressive symptoms, while depressive symptoms were associated with subsequent PIU and self-esteem.

In line with previous studies [40, 41], both PIU, self-esteem, and depressive symptoms exhibited considerable temporal stability from baseline to 2-year follow-up, emphasizing the core role of each domain in predicting the later

Table 5 Standardized parameter estimation for paths in Model 3 and Model 6

Paths	Model 3		Model 6	
	β (95% CI)	*P*	*β* (95% *CI*)	*P*
Within-time correlation				
t1 PIU with t1 SE	− 0.275 (− 0.323, − 0.227)	**< 0.001**	− 0.275 (− 0.323, − 0.227)	**< 0.001**
t2 PIU with t2 SE	− 0.121 (− 0.177, − 0.066)	**< 0.001**	− 0.119 (− 0.175, − 0.064)	**< 0.001**
t3 PIU with t3 SE	− 0.060 (− 0.113, − 0.007)	**0.028**	− 0.117 (− 0.170, − 0.064)	**< 0.001**
t1 SE with t1 DEP	− 0.616 (− 0.652, − 0.580)	**< 0.001**	− 0.616 (− 0.652, − 0.580)	**< 0.001**
t2 SE with t2 DEP	− 0.388 (− 0.449, − 0.327)	**< 0.001**	− 0.388 (− 0.448, − 0.329)	**< 0.001**
t3 SE with t3 DEP	− 0.509 (− 0.559, − 0.460)	**< 0.001**	− 0.441 (− 0.490, − 0.391)	**< 0.001**
t1 DEP with t1 PIU	0.400 (0.350, 0.449)	**< 0.001**	0.400 (0.350, 0.449)	**< 0.001**
t2 DEP with t2 PIU	0.293 (0.236, 0.350)	**< 0.001**	0.289 (0.232, 0.347)	**< 0.001**
t3 DEP with t3 PIU	0.190 (0.114, 0.265)	**< 0.001**	0.268 (0.207, 0.328)	**< 0.001**
Autoregressive path				
t1 PIU to t2 PIU	0.653 (0.610, 0.695)	**< 0.001**	0.647 (0.604, 0.690)	**< 0.001**
t2 PIU to t3 PIU	0.620 (0.573, 0.667)	**< 0.001**	0.619 (0.573, 0.665)	**< 0.001**
t1 SE to t2 SE	0.503 (0.439, 0.567)	**< 0.001**	0.487 (0.422, 0.551)	**< 0.001**
t2 SE to t3 SE	0.586 (0.523, 0.649)	**< 0.001**	0.574 (0.510, 0.639)	**< 0.001**
t1 DEP to t2 DEP	0.523 (0.465, 0.582)	**< 0.001**	0.501 (0.439, 0.562)	**< 0.001**
t2 DEP to t3 DEP	0.491 (0.427, 0.555)	**< 0.001**	0.468 (0.406, 0.531)	**< 0.001**
Cross-lag path				
t1 PIU to t2 SE	− 0.005 (− 0.048, 0.038)	0.814	− 0.003 (− 0.046, 0.041)	0.907
t1 PIU to t2 DEP	0.068 (0.021, 0.115)	**0.005**	0.066 (0.019, 0.113)	**0.006**
t1 SE to t2 PIU	− 0.017 (− 0.065, 0.031)	0.489	− 0.005 (− 0.053, 0.043)	0.840
t1 SE to t2 DEP	− 0.116 (− 0.173, − 0.059)	**< 0.001**	− 0.105 (− 0.164, − 0.047)	**< 0.001**
t1 DEP to t2 PIU	0.001 (− 0.057, 0.056)	0.994	− 0.012 (− 0.072, 0.047)	0.683
t1 DEP to t2 SE	− 0.108 (− 0.168, − 0.049)	**< 0.001**	− 0.089 (− 0.151, − 0.027)	**0.005**
t2 PIU to t3 SE	0.006 (− 0.036, 0.047)	0.784	0.012 (− 0.028, 0.052)	0.555
t2 PIU to t3 DEP	0.074 (0.022, 0.127)	**0.005**	0.067 (0.022, 0.113)	**0.004**
t2 SE to t3 PIU	0.050 (0.004, 0.096)	**0.034**	0.042 (− 0.005, 0.088)	0.078
t2 SE to t3 DEP	− 0.106 (− 0.172, − 0.039)	**0.002**	− 0.086 (− 0.151, − 0.021)	**0.009**
t2 DEP to t3 PIU	0.071 (0.018, 0.124)	**0.009**	0.074 (0.020, 0.129)	**0.007**
t2 DEP to t3 SE	− 0.02 (− 0.077, 0.037)	0.490	− 0.012 (− 0.068, 0.044)	0.673

Model 3 was the unadjusted model

Model 6 adjusted for sex, living arrangement, household socioeconomic status, academic pressure, classmate relationships, teacher-classmate relationships, and current alcohol consumption

PIU problematic Internet use, *SE* self-esteem, *DEP* depressive symptom, t1, t2, and t3 represented the assessment in baseline, 1-year follow up and 2-year follow up, respectively

development of the same domain. Moreover, the stability of PIU and depressive symptom was stronger in girls than boys [42, 43]. Regarding within-time associations among these three variables, we found that PIU was positively associated with depressive symptoms, and self-esteem was negatively associated with both PIU and depressive symptoms among adolescents at each time point, which was consistent with prior cross-sectional studies [13, 14, 24]. Besides, the strength of associations was stronger in girls than boys except for the association between PIU and self-esteem, supporting the findings of previous studies [24, 44].

Our study also showed 1-year cross-lag effects of PIU on depressive symptoms at each time point, indicating depressive symptoms in 1-year follow-up predicted PIU in 2-year follow-up, which was consistent with previous studies. The Tokyo Teen Cohort study observed the bidirectional associations between PIU and depressive symptoms among adolescents [45]. Similarly, in a longitudinal study in Hong Kong, we observed that Internet addiction at baseline could predict subsequent depressive symptoms while depressive symptoms at baseline were also associated with Internet addiction at follow-up [46]. The cross-lag associations reflected a spiraling effect between PIU and depressive symptoms. PIU was also associated with insufficient sleep duration and lower physical activities, which might increase the risk of depressive symptoms [18]. In addition,

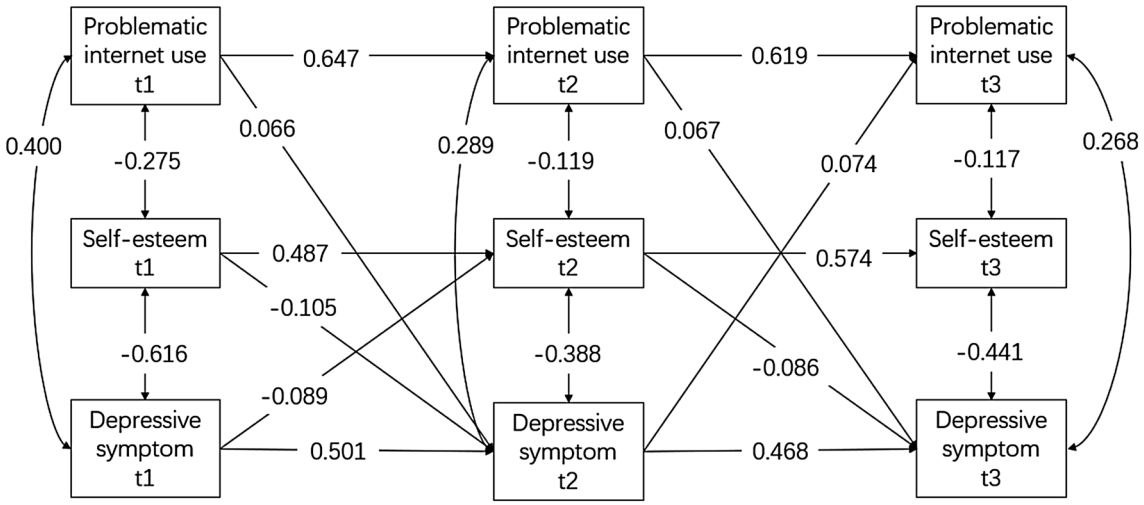

Fig. 1 The longitudinal associations between PIU, self-esteem and depressive symptoms (Model 6). t1, t2 and t3 represented the assessment in baseline, 1-year follow-up and 2-year follow-up, respectively. Model 6 was adjusted for sex, living arrangement, HSS, academic pressure, classmate relationships, teacher-classmate relationships, and current alcohol consumption. The value shown represented standardized coefficient and all pathways presented were statistically significantly ($P < 0.05$)

adolescents with depressive symptoms could exhibit persistent low mood, diminished interest, and interpersonal difficulties in real life [1]. Internet provided them with social and emotional support to mitigate interpersonal problems and stimulate their interest in exploring new things [47]. Therefore, adolescents with depressive symptoms were more likely to relieve their bad moods through inappropriate Internet use, which enabled them to be easily addicted to the Internet [48].

Additionally, we found similar associations between self-esteem and depressive symptoms. At each time point, self-esteem had a cross-lag effect on depressive symptoms, while depressive symptoms in baseline predicted self-esteem in 1-year follow-up. The associations were also observed in several studies. A cross-generational longitudinal study revealed a bidirectional association between self-esteem and depressive symptoms [22]. Besides, a meta-analysis also supported a bidirectional association between these two variables, and the predictive effect of self-esteem on depression was stronger [21]. Our findings supported both models, with the vulnerability model having a stronger effect. Adolescents are in the process of transitioning from childhood to adulthood and may experience maladjustment during this time which can damage their self-concept [3]. Consequently, they are at high risk of developing depressive symptoms due to lower self-esteem, and more severe depressive symptoms can in turn lead to a negative self-concept, which can further lower self-esteem.

Our study did not find any cross-lagged association between PIU and self-esteem, which was not similar to the previous findings. Donald et al. found that compulsive internet use (CIU) could cause a slight decrease in subsequent self-esteem among Australian adolescents [15]. PIU, like other addictions, could disrupt learning and other activities of daily life, resulting in a diminished sense of self-control [13]. The use of the Internet, especially social networking platforms, which involve social comparison, could lead to dissatisfaction with an individual's life and thus lower levels of self-esteem in adolescents [15]. However, our results did not support this idea. PIU might have affected self-esteem through other mechanisms, such as preference for different forms of Internet use (e.g., gaming and social networks). Future research could extend different forms of internet use for in-depth exploration. Donald also found that self-esteem did not predict subsequent PIU, which was consistent with our results [15]. These findings might be related to that CIU was driven more by environmental factors, such as social support and access to the Internet, rather than personality factors (self-esteem).

However, the results were contrary to our initial hypothesis that self-esteem played a mediator role in the association between PIU and depressive symptoms. The possible explanation was the short interval between our data collection and high within-time associations and temporal stability that might obscure the cross-lag effects [25]. Additionally, self-esteem may be differently associated with specific forms of internet use (a preference for gaming or smartphone use). A longitudinal study in China found that Internet Gaming Disorder (IGD) was negatively associated with subsequent self-esteem [17]. In another longitudinal study, Wartberg et al. reported that the self-esteem problem at t1 was a predictor at IGD at t2 [19]. Besides, Lee et al. followed up 56 adolescents with problematic smartphone use (PSU) for 6 months (35 for persistent addicted users and 21 for recovered users)

and found that the recovered group exhibited a higher level of self-esteem after 6 months [49]. These findings suggest that the persistence of PSU may have a significant impact on the developmental trajectory of self-esteem. Future studies could expand on different types of Internet use to explore this. In a word, the final results demonstrated that depressive symptom among adolescents might be the result of a combination of multiple pathways and underscored that depressive symptom was a multifactorial phenomenon. Therefore, interventions targeting PIU and self-esteem are urgently needed to reduce the risk of adolescents' adverse mental health outcomes.

There are several limitations to our study. First, data were collected via structured self-report questionnaires, which could not exclude the recall bias, although self-reporting is a widely accepted method. Second, the study sample was mainly derived from adolescents in school and did not include students absent from schools, and PIU, low self-esteem, and depressive symptoms might be more common among them. Third, although our study utilized a prospective study design, the follow-up period was not long (2 years). Considering the associations between PIU, self-esteem and depressive symptoms may be more dynamic, we could consider shorter measurement intervals in future studies. Despite these limitations, our study has several strengths. To our knowledge, it is the first study to explore the complex associations between PIU, self-esteem, and depressive symptom in a large sample of Chinese adolescents. Moreover, a robust analytic method was used in our study that could better explain the concurrent and longitudinal associations between PIU, self-esteem, and depressive symptom.

Conclusion

This longitudinal study provided evidence that problematic Internet use and low level of self-esteem could predict subsequent depressive symptoms among adolescents and vice versa. Depressive symptoms were also associated with subsequent PIU and self-esteem. Based on the findings, schools and parents should give more attention to adolescents prone to developing depressive symptoms, give them more social support to reduce their negative emotions and enhance their sense of self-concept. Health-related professionals should incorporate practical knowledge and skills into the education of adolescents to help them better control Internet use, attenuating the risk of future depressive symptoms.

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Availability of data and materials Not applicable.

Code availability Not applicable.

Declarations

Conflict of interest The authors declare no conflict of interest.

Ethics approval The research was conducted in accordance with the Declaration of Helsinki, and obtained ethical approval from Sun Yat-sen University, School of Public Health Institutional Review Board (Ethics Number: L2017060).

Consent to participate After the intention and procedure of this study had been fully explained in detail, written informed consent was obtained from each participating student and one of their parents or legal guardians.

Consent for publication Not applicable.

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