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ORIGINAL RESEARCH

The Links Among Cumulative Ecological Risk and Smartphone Addiction, Sleep Quality in Chinese University Freshmen: A Two-Wave Study

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Purpose: While previous research has highlighted the influence of family, school, and peer factors on smartphone addiction and sleep quality, the cumulative effects of these risk factors and their underlying causal relationships remain poorly understood. Therefore, based on the cumulative risk model and the bioecological model of human development, this study examined the longitudinal associations between cumulative ecological risk and smartphone addiction and sleep quality.

Methods: A survey was conducted among 653 Chinese university freshmen (mean age 18.56) at two distinct time points, with a 6-month interval. The initial assessment focused on family, school, and peer risk factors, while the subsequent assessment focused on smartphone addiction and sleep quality.

Results: Approximately 63.71% of university freshmen were found to be at risk of exposure. Compared to other risk-exposure groups, the group with no-risk exposure exhibited the lowest scores for smartphone addiction and sleep quality. The relationships between cumulative ecological risk and smartphone addiction and sleep quality displayed a linear pattern and a discernible "gradient effect". Smartphone addiction was identified as a fully mediating factor in the link between cumulative ecological risk and sleep quality, with a mediating effect value of 0.08 (representing 44.44% of the total effect).

Conclusion: University freshmen face various risks associated with their families, schools, and peers. The cumulative ecological risk can, directly and indirectly, impact sleep quality by influencing smartphone addiction. Given the observed "gradient effect" of cumulative ecological risk on smartphone addiction and sleep quality, it is imperative to adopt comprehensive risk prevention strategies to mitigate the impact of each risk factor.

Keywords: cumulative ecological risk, smartphone addiction, sleep quality

Introduction

A total of 5.44 billion people are using mobile phones in early 2023, constituting 68% of the global population.[1] The prevalence of smartphone addiction has increased globally,[2] particularly since the outbreak of the COVID-19 pandemic in 2020; there has been a notable increase in smartphone reliance and addiction.[3,4] Among the susceptible population, university students have raised significant concerns.[5,6] They heavily rely on cell phones for academic pursuits, daily routines, and social interactions, with smartphones becoming an integral part of their lives.[7] Nonetheless, smartphone addiction profoundly impacts sleep quality,[8] leading to various physical, psychological, and other associated issues.[9,10]

Cumulative Ecological Risk and Smartphone Addiction

According to the bioecological model of human development,[11,12] human development is influenced by multiple ecological subsystems, including family, school, and peers. Previous research has found that these factors influence smartphone addiction.

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Specifically, family risk factors play an essential role in individual smartphone addiction. Different parenting styles have different effects on individual addictive behaviors.[13] If parents fail to give their children emotional warmth and support, children are more likely to seek emotional comfort through smartphone use.[14] Poor family functioning has emerged as a risk factor for smartphone use problems among young people.[15]

Secondly, the influence of school risk factors on smartphone addiction cannot be ignored. It is well-known that university students study and reside primarily on campus. Poor peer and teacher-student relationships can weaken the emotional attachment of students to their school.[16] A self-determination theory explains that the behavior of an individual hinges on fulfilling basic psychological needs.[17] When risk factors increase, the gratification of psychological needs may decrease, thus increasing the propensity for smartphone addiction.

Finally, the influence of peer risk factors should also be emphasized. Good peer relationships are a protective factor against individual addiction,[18] whereas deviant peer affiliation may trigger more addictive behaviors.[19] According to social learning theory, individuals learn by observing and imitating the behaviors of others.[20] Interactions with delinquent peers may influence the values and behavioral norms of individuals, leading to imitation and reinforcement of smartphone dependence.

However, these studies have focused on the importance of a single or a few ecological risk factors, ignoring the cumulative effects of ecological risk factors across different domains. Only by simultaneously focusing on the effects of multidomain risk factors on developmental outcomes is it more accurately reflecting the realities of the lives of individuals.[21,22] Cumulative ecological risk refers to risk sources coming from multiple domains, for instance, peers, family, school, and community, in a person's living environment.[23] Evans et al (2013)[24] argued that the cumulative risk model is theoretically similar to the bioecological model of human development (which emphasizes the disruption of the continuous energy exchange between the organism and the environment by the accumulation of multiple risk factors, which is necessary for the healthy development of the individual). To date, several studies have explored the relationship between cumulative risk and various psychopathological problems based on this model;[25,26] however, the relationship between cumulative ecological risk and smartphone addiction and sleep quality as received less attention.

Additionally, this study explored the functional relationship between cumulative ecological risk and smartphone addiction. Exploring the functional form is essential because different forms often imply significantly different practical implications.[21] Numerous studies have suggested that the relationship between cumulative risk and individual development may take three different functional forms.[22,27–29] The first functional form is the positive acceleration model. This model assumes that the association between each risk factor and development outcomes is stronger when additional risk factors are present than when they are absent. The second form of functionality is the model of negative acceleration. This model suggests that as the number of risks increases, the effect of additional risk factors on individual development diminishes. The third functional form is the linear model. This model assumes that a one-unit increase in the number of risk factors corresponds to a one-unit increase in the psychopathology problem, exhibiting a "gradient effect".

Hypothesis 1: Cumulative ecological risk influences smartphone addiction.

Cumulative Ecological Risk and Sleep Quality

Sleep is an integral part of life, and it can reflect the health status of a person.[30] Poor sleep quality is common among university students, increasing the risk of mental illness and poor academic performance.[31]

Like the factors influencing smartphone addiction, family, school, and peer factors can affect sleep quality. Specifically, family risk factors influence sleep quality. Sleep and mood are closely related,[32,33] and the emotional warmth of parents can bring emotional stability to their children, which can help with sleep.[34] A four-year longitudinal study found that parental warmth during adolescence protected sleep in early adulthood.[35] A recent systematic review and meta-analysis suggested that fixed bedtimes and parental modeling of healthy sleep practices within an emotionally warm and functional family environment protected adolescent sleep duration, quality, and daytime functioning.[36] Besides family, school factors are also strongly associated with student sleep.[37] Holdaway and Becker (2018)[38] found that sleep problems in children are associated with weaker student–teacher relationships. According to the stress-buffering model, social support mitigates the effects of stress,[39] and higher levels of navigational social support help with sleep.[40] If

students cannot get support from teachers and peers at school, it may cause stress[41] and sleep problems. Finally, the influence of peer risk factors on sleep quality is also crucial. Positive peer relationships are associated with improved sleep.[42] A meta-analysis showed that peer victimization was associated with increased sleep problems and that sleep problems may be a sign that a child is being victimized by peers.[43]

However, these studies have focused primarily on the role that a single factor or risk factors within a domain play in sleep quality and have not emphasized the cumulative effects of risk factors across multiple domains. Therefore, it is imperative to investigate the impact of cumulative ecological risk on sleep quality.

Hypothesis 2: Cumulative ecological risk affects sleep quality.

Smartphone Addiction and Sleep Quality

Established studies have shown a strong relationship between smartphone addiction and sleep quality.[44–46] Those with a higher propensity for smartphone addiction report lower sleep quality.[47]

Smartphone addicts typically strongly rely on their phones and uncontrollable use behaviors.[48,49] They often sleep with their cell phones at the head of their beds or on their beds, allowing them to check the latest news or play games anytime. This behavior tends to blur the line between work/leisure and sleep environments. Additionally, the short wavelength light emitted by smartphone screens can affect sleep quality by inhibiting melatonin in people who use these devices at night.[50] Smartphone backlights may disrupt circadian rhythms, leading to negative sleep consequences, including going to sleep later than planned and thus reducing overall sleep time.[51] Furthermore, addiction alters the cognitive, emotional, and behavioral response patterns of an individual.[3,52] When addicted individuals use their smartphones in bed, they may be attracted to stimulating and arousing content, prolonging bedtime and reducing the efficiency of falling asleep. Additionally, persistent smartphone use may trigger feelings of anxiety,[53] which in turn affects sleep quality. Accordingly, we formulated hypothesis 3 of this study.

Hypothesis 3: Smartphone addiction affects sleep quality.

The mediating role of smartphone addiction in the relationship between cumulative ecological risk and sleep quality

It is well known that smartphone addiction is a manifestation of a person's behaviour in the waking state, whereas sleep quality is a high or low quality of a person's sleep. In accordance with the theory of cumulative ecological risk, the aggregation of various ecological risks experienced by individuals throughout their lives can have a detrimental impact on their behavior and development.[21–26] Furthermore, according to the self-regulation theory, risk information activates a coping program in individuals.[54] Conversely, smartphone addiction may be a strategy for frequent smartphone users to manage risk, impairing their self-regulating ability,[47] making them more susceptible to stress, and ultimately affecting sleep quality. That is, individuals with a high risk of exposure are more likely to tend to rely on their smartphones than those with a low risk of exposure, thus affecting the quality of their sleep. Therefore, smartphone addiction may mediate between cumulative ecological risk and sleep quality.

Hypothesis 4: Cumulative ecological risk may not only directly affect sleep quality but also indirectly affect sleep quality through smartphone addiction.

The Current Study

Most previous studies examining the association between cumulative ecological risk and individual development utilized cross-sectional research designs. However, such designs pose challenges in establishing a causal relationship between the two variables. Additionally, compared to students in high grades, university freshmen who have just entered the university campus face a change in role and an entirely unfamiliar setting. This transition can be a stressful experience,[55] rendering them more prone to smartphone addiction[22] and lower sleep quality.[56]

Therefore, based on the cumulative risk model and the bioecological model of human development, the present study selected university freshmen as the research object and adopted a research design including two time points to explore the ecological risk factors faced by these students, the form of cumulative ecological risk as a function of smartphone addiction and sleep quality, and the mechanism of the role of cumulative ecological risk in influencing smartphone addiction and sleep quality, to assist university freshmen to better cope with smartphone addiction and improve their sleep quality.

Methods

Participants

This study used convenience sampling to select university freshmen from Hunan Province, China. A total of 739 students participated in the initial measurement (T1) conducted in October 2022. Six months later, in April 2023, 653 students participated in the subsequent measurement (T2). In the valid sample, 171 (26.19%) were male and 482 (73.81%) were female. The mean age was 18.56 (*SD* = 0.65).

The attrition rate of the sample was 11.64%. The results of the independent samples *t*-test indicated a significant difference between the attrition sample and the follow-up sample regarding emotional warmth from the Father (t = –0.41, $p = 0.69$), emotional warmth from the mother ($t = –0.45$, $p = 0.65$), family functioning ($t = 0.67$, $p = 0.50$), peer support ($t = 0.25$, $p = 0.80$), teacher support ($t = –0.17$, p=0.87), school belonging ($t = 0.67$, $p = 0.50$), peer attachment ($t = –0.64$, $p = 0.52$), and friend support ($t = –0.34$, $p = 0.73$). However, a significant difference was observed only in the case of bad peer interactions ($t = 2.56$, $p < 0.05$). These results indicated that there was no significant structural attrition in the sample of this study.

Measures

Cumulative Ecological Risk

This study aimed to construct a cumulative ecological risk index by selecting nine risk factors in family, school, and peers, which are closely associated with smartphone addiction and sleep quality among university freshmen. Each ecological risk factor was measured as follows.

(1) Father's emotional warmth. This research utilized the Emotional Warmth of Father subscale of the Short-form Parenting Styles Scale.[57,58] It contains seven items measured on a 4-point Likert scale. Higher scores indicate higher levels of the Father emotional warmth. The questionnaire had a high internal consistency with an alpha coefficient of 0.92 in this study.

(2) Mother's emotional warmth. This research utilized the Emotional Warmth of Mother subscale of the Short-form Parenting Styles Scale.[57,58] It contains seven items measured on a 4-point Likert scale. Higher scores indicate higher levels of maternal emotional warmth. The questionnaire demonstrated good internal consistency with an alpha coefficient of 0.91 in this study.

(3) Family functioning. The General Functioning subscale of the Family Functioning Rating Scale[59,60] was used in this study. It contains 12 items measured on a 4-point Likert scale. The scoring of reverse-scored and positive-scored questions was reversed. Higher scores indicated better family functioning. The questionnaire showed satisfactory internal consistency with an alpha coefficient of 0.86 in this study.

(4) Classmate support. This study utilized the Classmate Support subscale of the School Connection Scale.[61] It contains four items measured on a 5-point Likert scale. Higher scores indicate higher levels of peer support. The questionnaire exhibited acceptable internal consistency with an alpha coefficient of 0.68 in this study.

(5) Teacher support. The Teacher Support subscale of the School Connection Scale[61] was used in this study. It includes three items measured on a 5-point Likert scale. Higher scores indicate higher levels of teacher support. The questionnaire demonstrated moderate internal consistency with an alpha coefficient of 0.62 in this study.

(6) School belonging. The School Affiliation subscale of the School Affiliation Scale[61] was used in this study. It contains three items measured on a 5-point Likert scale. Higher scores indicate a higher degree of school belonging. The questionnaire displayed acceptable internal consistency with an alpha coefficient of 0.75 in this study.

(7) Peer attachment. The Peer Attachment subscale of the Parent and Peer Attachment Scale[62,63] was used in this study. It contains 12 items measuring trust, communication, and detachment on a 5-point Likert scale. Higher scores indicate higher levels of peer attachment. The questionnaire demonstrated good internal consistency with an alpha coefficient of 0.85 in this study.

(8) Friend support. The Friend Support subscale of the Comprehension Social Support Scale[64,65] was used in this study. It contains four items measured on a 5-point Likert scale. Higher scores indicate higher levels of friend support. The questionnaire exhibited excellent internal consistency with an alpha coefficient of 0.93 in this study.

(9) Deviant peer affiliation. Eight items were selected based on previous studies.[66,67] Participants were asked to indicate the frequency of their friends engaging in specific behaviors in the past year (for example, smoking, drinking, cheating on exams). A 5-point Likert scale was used for response options. Higher scores indicate a higher level of association with undesirable peers. The questionnaire demonstrated good internal consistency with an alpha coefficient of 0.86 in this study.

The present study classified the nine ecological risk factors into three categories: family factors (emotional warmth of a father, emotional warmth of a mother, and family functioning), school factors (classmate support, teacher support, and school belonging), and peer factors (peer attachment, friend support, and deviant peer affiliation).

This study followed a previously published widely accepted modeling approach to construct the Cumulative Ecological Risk Index.[23,68] Table 1 presents the methodology employed in the study. Specifically, for each risk variable, the 25th or 75th percentile score served as the cutoff, and participants were categorized as \"at risk\" (score of 1) or \ "not at risk\" (score of 0). The scores of all risk factors were subsequently summed to calculate the cumulative ecological risk index.

Smartphone Addiction

The Smartphone Addiction Scale Short Version (SAS-SV)[69] was used in this study. The scale contains 10 items and is unidimensional. Participants rated their responses on a 6-point Likert scale, with a higher score indicating a greater inclination towards smartphone addiction. The internal consistency of the scale in this study was satisfactory, with an alpha coefficient of 0.87.

Sleep Quality

The Pittsburgh Sleep Quality Index (PSQI)[70] was used in this study. It comprises 18 items and assesses seven dimensions of sleep quality, including sleep quality, latency, duration, efficiency, disturbances, use of sleeping medication, and

Table 1 Description of Ecological Risk Factors and Definition of Cumulative Contextual Risk

Risk Factor	Risk Area	*M* (*SD*)	Items	Scoring Method	Criteria for Defining Risk	Percentage of Risk
1.Father's emotional warmth	Family	2.93 (0.71)	7	1 (never) ~ 4 (always)	Below 25th percentile	22.51
2.Mother's emotional warmth	Family	3.07 (0.67)	7	1 (never) ~ 4 (always)	Below 25th percent	20.67
3.Family functioning	Family	3.08 (0.47)	12	1 (strongly agree) ~ 4 (strongly disagree)	Below 25th percentile	19.60
4.Classmate support	School	3.81 (0.59)	4	1 (strongly disagree) ~ 5 (strongly agree)	Below 25th percentile	20.21
5.Teacher support	School	4.03 (0.57)	3	1 (strongly disagree) ~ 5 (strongly agree)	Below 25th percentile	17.76
6.School belonging	School	3.83 (0.66)	3	1 (strongly disagree) ~ 5 (strongly agree)	Below 25th percentile	15.47
7.Peer attachment	Peer	3.78 (0.53)	12	1 (almost never or never true) ~ 5 (almost always or always true)	Below 25th percentile	23.74
8.Friend support	Peer	3.96 (0.78)	4	1 (completely inconsistent) ~ 5 (fully consistent)	Below 25th percentile	17.30
9.Deviant peer affiliation	Peer	1.43 (0.52)	8	1 (never) ~ 5 (almost all)	Above 75th percentile	21.75

Number of risk factors	0	1	2	3	4	5	6	7	8	9
Percentage	36.29	21.75	12.56	10.26	6.74	5.36	2.45	3.83	0.76	0.00

daytime dysfunction. Each dimension is scored on a scale of 0 to 3, and the scores are summed to yield a total sleep quality score (PSQI). Higher scores indicate poorer sleep quality. The scale demonstrated satisfactory internal consistency in this study, with an alpha coefficient of 0.83.

Procedure

The data collection took place when students were in intensive classes. The cumulative ecological risk was measured during the first time (October 2022), whereas smartphone addiction and sleep quality were evaluated during the second time (April 2023). Participation in the study was voluntary, and participants had the right to withdraw at any time.

Ethical Considerations

The study was conducted according to the guidelines of the Declaration of Helsinki, and approved by the Academic Committee of the School of Preschool Education, Changsha Normal University.

Data Analysis

The study eliminated extreme values during the data cleaning process and employed the Expectation Maximization Algorithm to estimate missing values. Data analysis was conducted using SPSS 26.0 for frequency analysis, descriptive statistics, correlation analysis, *t*-tests, ANOVA, and regression analysis. Mediation analysis was conducted using Model 4 in the PROCESS 4.2 macro program. The Raincloud Plot was created using JASP 0.17.2.1. Additionally, Harman's one-factor test was performed to examine common method bias, and the results showed that there were 15 factors with eigenvalues > 1, with the first factor accounting for 22.16% of the variance, indicating the absence of significant common method bias in the study.

Results

Construction of Cumulative Ecological Risk Index

As shown in Table 1, the rates of exposure to various types of risks among university freshmen were higher for peer attachment risk (23.74%), followed by father's emotional warmth risk (22.51%) and deviant peer affiliation risk (21.75%). Upon detailed examination of the cumulative risk index, it was found that 36.29% of the participants were not exposed to any risk, while the remaining 63.71% were exposed to some risk. Of these, 44.57% were exposed to one to three risks concurrently, while 19.14% faced four or more risks simultaneously.

The participants of this study were divided into three groups according to the number of risks they were exposed to (group with no risk, group with 1~3 risks, and group with four or more risks). The one-way ANOVA analysis showed that all three groups exhibited statistically significant differences in smartphone addiction ($F(2584) = 8.36$; $p < 0.001$; $\eta_p^2 = 0.03$) and sleep quality ($F(2530) = 4.35$; $p < 0.05$; $\eta_p^2 = 0.02$). The results of multiple comparisons showed that on the smartphone addiction score (Figure 1), the group with no risk ($M\pm SD = 3.10\pm0.82$) was significantly lower than the group with four and more risks ($M\pm SD = 3.47\pm0.81$), $p < 0.001$; group with 1~3 risks ($M\pm SD = 3.15\pm0.85$) was significantly lower than group with 4 and more risks, $p < 0.01$; group with no risk insignificantly different from group with 1~3 risks, $p > 0.05$. On the score of sleep quality (Figure 2), group with no risk ($M\pm SD = 5.56\pm2.75$) was significantly lower than group with four and more risks ($M\pm SD = 6.57\pm3.08$), $p < 0.05$; there was no significant difference between group with 1~3 risks ($M\pm SD = 6.08\pm2.90$) and group with four and more risks, $p > 0.05$; and there was no significant difference between group with no risk and group with 1~3 risks, $p > 0.05$.

Descriptive Statistics and Correlation Matrix of Key Variables

The Person product difference correlation analysis of the main variables, as shown in Table 2, indicated a significant negative correlation between gender and smartphone addiction ($p < 0.05$) but not a significant correlation with sleep quality ($p > 0.05$). The cumulative ecological risk demonstrated a significant positive correlation with both smartphone addiction and sleep quality ($p < 0.01$).

Furthermore, cumulative school and peer risks were significantly positively correlated with smartphone addiction and sleep quality ($p < 0.05$). Although the correlation between cumulative family risk and smartphone addiction and sleep

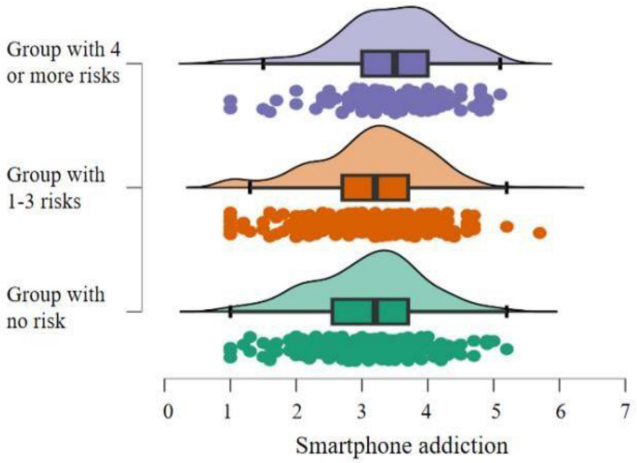

Figure 1 Comparison of smartphone addiction across different risk groups.

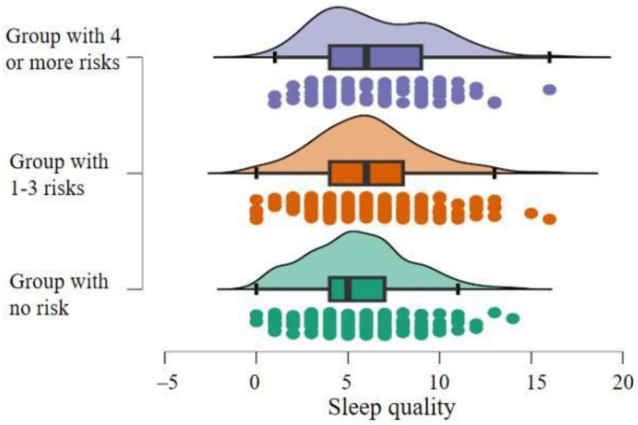

Figure 2 Comparison of sleep quality across different risk groups.

quality was not significant ($p > 0.05$), the significant correlation between family risk factors and the other risk factors (Table 3) and the synergistic nature of risk factors[23] led to the retention of family risk factors in this study.

Relationship Between Cumulative Ecological Risk and Smartphone Addiction

Stratified regression analysis was conducted to examine whether the primary (cumulative ecological risk) and the secondary term significantly predicted smartphone addiction. Initially, regression analyses were performed with smartphone addiction as the dependent variable, controlling for gender and age, while using cumulative ecological risk as the predictor variable.The results in Table 4 demonstrated that after controlling for the effects of gender and age, cumulative

Table 2 Descriptive Statistics and Correlation Matrix of Key Variables

	M±SD	Skewness	Kurtosis	1	2	3	4	5
1.Gender	—	—	—	1				
2.Cumulative ecological risk (T1)	1.79±2.03	1.15	0.49	0.13***	1			
3.Age (T2)	18.56±0.65	0.28	0.39	0.07	–0.02	1		
4.Smartphone addiction (T2)	3.20±0.84	–0.37	0.14	–0.08*	0.14***	0.03	1	
5.Sleep quality (T2)	5.98±2.90	0.42	0.13	–0.06	0.12**	0.01	0.39***	1

Notes: Gender: 0=Female, 1=Male; *p<0.05, **p<0.01, ***p<0.001.

Table 3 Correlation Between Ecological Risk Factors

	1	2	3	4	5	6	7	8	9
1.Father's emotional warmth	1								
2.Mother's emotional warmth	0.83***	1							
3.Family functioning	0.65***	0.64***	1						
4.Classmate support	0.24***	0.26***	0.30***	1					
5.Teacher support	0.31***	0.28***	0.32***	0.48***	1				
6.School belonging	0.30***	0.29***	0.36***	0.53***	0.66***	1			
7.Peer attachment	0.35***	0.38***	0.39***	0.52***	0.35***	0.43***	1		
8.Friend support	0.26***	0.27***	0.29***	0.42***	0.24***	0.27***	0.59***	1	
9.Deviant peer affiliation	–0.09*	–0.07***	–0.14***	–0.19***	–0.12**	–0.11**	–0.28***	–0.23***	1

Note: *p<0.05, **p<0.01, ***p<0.001.

Table 4 Relationship Between Cumulative Ecological Risk and Smartphone Addiction

	R^2	ΔR^2	F	B	95% CI
Step 1	0.01	0.01	2.62		
Gender				–0.18*	[–0.35, –0.01]
Age (T2)				0.04	[–0.06, 0.15]
Step 2	0.03	0.03	5.80***		
Cumulative ecological risk (linear term)				0.06***	[0.03, 0.09]
Step 3	0.03	0.02	4.35**		
Cumulative ecological risk (quadratic term)				0.01	[–0.02, 0.02]

Notes: *p<0.05, **p<0.01, ***p<0.001; 95% confidence intervals with predictors were obtained by Bootstrap method.

ecological risk (linear term) significantly and positively predicted smartphone addiction ($p < 0.001$). This indicated that a higher cumulative ecological risk was associated with a greater degree of smartphone addiction.

A quadratic term was added to the linear term to explore the relationship further. If the regression coefficient of the quadratic term is not significant, it signifies a linear pattern. Conversely, if the regression coefficient is significant, it indicates a nonlinear relationship between cumulative ecological risk and the outcome variable.[71] However, in this study, the predictive effect of the quadratic term was not significant, suggesting the linear relationship between cumulative ecological risk and smartphone addiction.

Relationship Between Cumulative Ecological Risk and Sleep Quality

A stratified regression analysis was performed to examine the predictive effect of cumulative ecological risk on sleep quality. The analysis included sleep quality as the dependent variable, gender and age as control variables and cumulative ecological risk (linear term) as the predictor variable. Table 5 demonstrates that cumulative ecological risk (linear term) significantly and positively predicted sleep quality ($p < 0.001$) even after considering the effects of gender and age on sleep quality. This suggests that higher cumulative ecological risk is associated with poorer sleep quality. Furthermore, a quadratic term was added to the

Table 5 Relationship Between Cumulative Ecological Risk and Sleep Quality

	R^2	ΔR^2	F	B	95% CI
Step 1	0.01	0.01	1.17		
Gender				–0.44	[–1.05, 0.11]
Age (T2)				0.05	[–0.35, 0.41]
Step 2	0.02	0.01	3.41*		
Cumulative ecological risk (linear term)				0.18**	[0.04, 0.30]
Step 3	0.02	0.01	2.56*		
Cumulative ecological risk (quadratic term)				0.01	[–0.06, 0.07]

Notes: *p<0.05, **p<0.01; 95% confidence intervals with predictors were obtained by Bootstrap method.

model, but its predictive effect was insignificant, indicating that the linear relationship best represents the relationship between cumulative ecological risk and sleep quality.

Mediating Role of Smartphone Addiction

Model 4 in the PROCESS macro program was used to examine the mediating effect of smartphone addiction between cumulative ecological risk and sleep quality. The results in Figure 3 indicated that after including gender, age (T2), cumulative ecological risk (T1), and smartphone addiction (T2) in the regression equation, smartphone addiction significantly predicted sleep quality ($B = 1.34$; $p < 0.001$; Bootstrap 95% CI = [1.02, 1.63]). Interestingly, the effect of cumulative ecological risk on sleep quality was insignificant ($B = 0.11$; $p > 0.05$; Bootstrap 95% CI = [−0.02, 0.24]). Moreover, the mediating effect of smartphone addiction was significant, with an effect size of 0.08 (representing 44.44% of the total effect), Bootstrap 95% CI = [0.03, 0.13]. Therefore, these results suggested that smartphone addiction fully mediated the relationship between cumulative ecological risk and sleep quality.

Discussion

Based on the cumulative risk model and the bioecological model of human development, this study embarked on a novel examination of the vertical association between cumulative ecological risk and smartphone addiction and sleep quality, employing a research design spanning two time points and an inclusive selection of representative ecological risk factors. This investigation shed light on the mechanism of action underlying cumulative ecological risk and yielded noteworthy and valuable findings.

The relationship between cumulative ecological risk and smartphone addiction and sleep quality

First, this study found a significant adverse effect of cumulative ecological risk on smartphone addiction, confirming the cumulative risk model and the validity of hypothesis 1. This finding is consistent with the results of existing studies on the relationship between cumulative ecological risk and addiction.[21,22] Evans et al (2013)[23] stated that multiple-risk factor exposure has more severe and unfavorable consequences than single-risk factor exposure. This study further found that the no-exposure risk group had the lowest smartphone addiction scores compared to the other exposure risk groups. In the exposure risk group, university freshmen constantly faced challenges from risk factors, including family, school, and peers. It is difficult for them to overcome these challenges. Particularly, peer affiliation has a strong influence on university students[72,73] and is a protective factor against smartphone addiction,[18] whereas deviant peer affiliation exacerbates addictive behaviors.[74]

Additionally, this study found that cumulative ecological risk significantly affected sleep quality, validating the cumulative risk model and the validity of hypotheses 2. It was consistent with existing research findings.[75,76] Furthermore, the no-exposure-risk group had the lowest sleep quality scores compared to the other exposure-finding

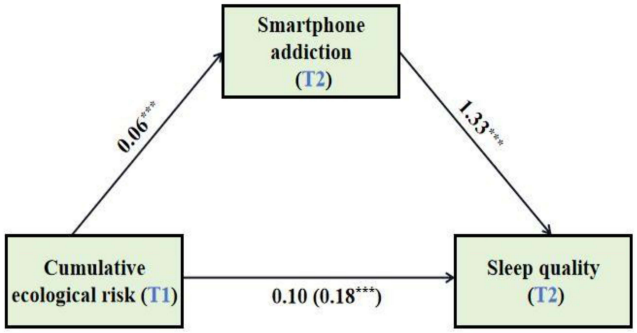

Figure 3 Mediating role of smartphone addiction.
Note: ***p<0.001.

groups. Cumulative risk may affect sleep quality by inducing physical and psychological stress responses,[77] disrupting the bioregulatory system of an individual,[23] and causing disruption of the biological clock, increasing cognitive stress, and environmental disturbances. A study assessing the occurrence of significant trajectories of sleep problems in children from birth to age 10–11 years found that cumulative risk was associated with all trajectories of sleep problems.[78]

Lastly, the study confirmed the validity of hypothesis 3 and hypothesis 4. Smartphone addiction may act as a bridge for the mediating variable that lies between cumulative ecological risk and sleep quality. A recent meta-analysis of 29 studies showed that cell phone addicts were at higher risk of developing sleep disorders.[79] They devote significant time and energy to cell phone use,[80] reducing their sleep time. This time conflict may lead to insufficient sleep time and low sleep quality. Additionally, smartphone use may lead to exposure to blue light and stimulating content,[81,82] which may affect sleep latency and quality.

Practical Significance

The findings of this study have important implications for preventing and intervening in smartphone addiction and improving sleep quality among university freshmen.

Firstly, it is vital to consider the impact of cumulative ecological risk in promoting the physical and mental health development of university freshmen. This study found that nearly 70% of university freshmen had exposure risks. Among them, three types of exposure risks had higher percentages, including exposure to peer attachment risk, exposure to father emotional warmth risk, and exposure to bad peers. Therefore, in the future, besides strengthening family education (emphasizing the important role of fathers in parent-child relationships), it is imperative to guide university freshmen in acquiring effective interpersonal skills to establish good peer relationships.

Secondly, consider the impact of each risk factor on smartphone addiction. Given the "gradient effect" between cumulative ecological risk and smartphone addiction among university freshmen, we must consider any risk factor that affects smartphone addiction. This is because reducing the impact of even a single risk factor may play an important role in preventing and intervening in smartphone addiction.

Again, the impact of each risk factor on sleep quality is emphasized. Given that this study found a "gradient effect" between cumulative ecological risk and smartphone addiction among university freshmen, we cannot ignore any risk factors affecting sleep quality. Moreover, since sleep quality is closely related to the physical and mental health of an individual,[83] it is important to minimize the effect of each risk factor on sleep quality.

Finally, active prevention and intervention of smartphone addiction improves the sleep quality of university freshmen. As this study found that smartphone addiction can completely mediate the relationship between cumulative ecological risk and sleep quality, we can begin addressing the relationship between cumulative ecological risk and sleep quality by preventing and intervening smartphone addiction and guiding university freshmen to use smartphones sensibly from cognitive, emotional, and behavioral perspectives to improve their sleep quality.

Limitations and Future Directions

This study has several limitations. Firstly, this study assessed smartphone addiction and sleep quality concurrently, making it challenging to establish a causal relationship between these variables. Future research could adopt a longitudinal approach with multiple time points to better comprehend the causal association between smartphone addiction and sleep quality. Secondly, while the ecological risk factors selected for this study were representative, not all potential risk factors were incorporated. Therefore, future research should focus on investigating these additional ecological risk factors. Thirdly, this study assessed only the impact of ecological risk factors on smartphone addiction and sleep quality without considering the potentially mitigating effect of protective factors that individuals apply against cumulative ecological risk. Moreover, the alpha coefficient of the instrument measuring teacher support risk in this study was not high. Future research should strive to unravel the combined effects of ecological risk factors and individual protective factors. Fourthly, it is important to note that there is a higher number of female samples in this study, therefore caution is needed in generalizing the findings.

Conclusion

University freshmen face various risks associated with their families, schools, and peers.

Cumulative ecological risk can not only directly affect the sleep quality of university freshmen, but also indirectly by affecting smartphone addiction. Moreover, given the observed "gradient effect" of cumulative ecological risk on smartphone addiction and sleep quality, it is imperative to adopt comprehensive risk prevention strategies to mitigate the impact of each risk factor.

Data Sharing Statement

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

Informed Consent

All participants participating in our study provided informed consent prior to study participation. They agreed to participate and signed an informed consent form. Informed consent procedures were used to collect all study data.

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Disclosure

The authors report no conflicts of interest in this work.

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