International Journal of Mental Health Promotion

Tech Science Press

DOI: 10.32604/ijmhp.2024.030209

ARTICLE

Relationships among Sedentary Time, Electronic Product Addiction, and Depression in Adolescents during the COVID-19 Epidemic: A Cross-Lagged Study

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Received: 26 March 2023 Accepted: 16 January 2024 Published: 08 April 2024

ABSTRACT

Objective: This study was conducted to explore the relationships among sedentary behavior (SB), electronic product addiction (EPA), and depression (D) in adolescents during the COVID-19 epidemic. **Methods:** A total of 604 adolescents (including 309 girls and 295 boys aged 12–18) were selected from Qufu City, Shandong Province, China for three rounds of investigation. The model was constructed using AMOS 23.0 software, and cross-lagged analysis was conducted. **Results:** SB at T1 can significantly positively predict SB and EPA at T2 ($p < 0.05$). EPA at T1 can significantly positively predict SB and D at T2 ($p < 0.05$). Physical activity level and SB at T2 can significantly predict SB and EPA at T3 ($p < 0.05$). EPA at T2 can significantly predict SB, EPA, and D at T3 ($p < 0.05$). **Conclusions:** SB and EPA are predictive factors for D. Moreover, SB can significantly positively predict D and indirectly predict D through the mediating effect of EPA.

KEYWORDS

COVID-19; electronic product addiction; depression; sedentary behavior

Introduction

The global prevalence of COVID-19 has not only threatened children's and adolescents' physical health, but also indirectly affected their lifestyle and mental health as a result of the prevention and control measures such as at-home quarantine. Severe depression (D) and anxiety increased by 28% and 26%, respectively, worldwide in 2020, with a significant rise in incidence in countries seriously affected by COVID-19 [1–3]. In particular, the incidences of anxiety and D in children and adolescents in China were 26% and 29%, respectively, during the COVID-19 epidemic. Compared with children, adolescents had a higher incidence of D and anxiety symptoms [4]. Adolescent D is a syndrome characterized by low mood and loss of pleasure, and exerts many negative effects on adolescents' study, life, and development [5]. The potential risk of infection by COVID-19 and the widely implemented prevention and control measures such as at-home quarantine have brought great changes in lifestyle, which has caused new negative effects on children's and adolescents' mental health or exacerbated their existing mental health problems. For example, it has led to an increase in the detection rate of D [6–8]. D is a kind of emotional disorder dominated by dejection and loss of interest. In severe cases, it undermines people's physical and mental functions and social adaptation, which is highly detrimental to individual development [9]. The prevalence of adolescent D in China has reached 15%–20% [10]. D and anxiety were already common before the outbreak of COVID-19. According to

the Global Burden of Disease Study, D and anxiety were among the top 25 of the burden of disease in 2019. With the continuous spread of COVID-19, the incidence of D and anxiety may continue to increase. Therefore, D in adolescents during the COVID-19 period must be examined, and the influence of their behavior and lifestyle on their D symptoms must be explored [1].

In recent years, more attention has been paid to the problem of sedentary behavior (SB) among adolescents. SB refers to any conscious behavior characterized by energy consumption ≤1.5 metabolic equivalent in the state of sitting, leaning, or lying [11]. A significant positive correlation exists between SB and adolescent obesity, while obesity and overweight are high risk factors for type 2 diabetes, hypertension, asthma, and cancer [12,13]. In addition, SB is significantly correlated with D and anxiety symptoms in adolescents, and the score in D is higher when sedentary time is longer [14]. During the COVID-19 period, close contact tracking and social isolation were the most effective measures to control the spread of the virus. Maintaining "spatial distance" requires establishing and keeping a safe distance between individuals and reducing the number of close contacts [15]. The resulting regulations and suggestions include the temporary closure of educational institutions, recreational venues, and fitness venues. Under the epidemic situation, adolescents were subject to at-home restrictions or social isolation to prevent the spread of COVID-19. According to the data released by the Ministry of Education, about 100 million adolescents in China were restricted from going out because of the epidemic [16]. These measures and responses were quite necessary, but long-term isolation at home might increase SB among adolescents. Jiao et al. found that due to the suspension of classes and isolation at home during the COVID-19 pandemic, the extension of SB had a negative effect on the psychological state of adolescents, giving rise to psychological problems such as D and anxiety [17].

While the physical activity of adolescents gradually decreased, their time and frequency of using electronic products gradually increased. Especially since 2020, due to the epidemic-triggered at-home isolation and online learning, the physical activity of adolescents has significantly decreased, whereas their use of electronic products, one of the main forms of SB, has increased significantly. According to the characteristics of SB, adolescent SB can be divided into five categories: education-, culture-, sociality-, transportation-, and video-focused SBs. Education-, sociality-, and video-focused SBs are the main forms of adolescent SB at present [18]. Video-focused SB, characterized by the use of electronic products, brings more serious harm to adolescents. Long screen use is associated with low self-esteem, antisocial behavior, and metabolic risk diseases [19]. Guo et al. [20] found video-focused SB has a significant predictive effect on the weakening of adolescents' act of will. Longer use of electronic products increases D, anxiety symptoms, and school life dissatisfaction in adolescents [21].

In summary, on the one hand, the effect of SB on adolescents' physical and mental health may be related to obesity, overweight, and other problems caused by low energy consumption as well as the resulting high disease risk, low self-esteem, and poor interpersonal skills; on the other hand, it may be related to D, anxiety, and other emotional problems caused by electronic product addiction (EPA). Therefore, a cross-lagged design was adopted in this paper. Adolescents' SB and EPA were the independent variables, and D was the dependent variable to investigate SB, EPA, and D in adolescents during the COVID-19 epidemic and explore their internal relationships and interaction mechanism. The results of this study are conducive to the intervention on and the response to mental and psychological problems under any dynamic epidemic situation.

Methods

Participants

With reference to the definition of adolescents in adolescent psychology and exercise physiology, students aged 12–18 years or middle school and high school students, were selected as the research participants. According to the principle of convenience sampling, adolescents were selected from two middle schools in Shandong Province to conduct a one-semester and three-time longitudinal follow-up survey. The Time 1 (T1) survey was conducted in March 2022, the Time 2 (T2) survey was conducted in May 2022, and the Time 3 (T3) survey was conducted in July 2022. A total of 627 copies of the questionnaire were distributed, and 604 copies were completed in all the three times, which included 309 boys and 295 girls (age mean 14.82 ± 1.94). Permission was obtained from each volunteer before the survey, showing all of them took part in the study voluntarily. Permission was also obtained from relevant school administrators and head teachers.

Measuring instruments

Three scales were used in this study: International Physical Activity Questionnaire Short (IPAQ-S), Mobile Phone and Other Electronic Product Addiction Inventory, and Depression Subscale of Achenbach Self-rating Adolescent Behavior Scale.

(1) IPAQ-S [22]: This Chinese version of IPAQ-S was revised by Chinese scholars Qu et al. [22] and used to measure the participants' SB. IPAQ-S is one of the internationally recognized effective, widely used scales for measuring adult physical activity level. The applicable age for IPAQ-S is 15–69 years old. It covers seven items, among which six items are about individual physical activity, and asks participants to select low, medium, and high levels of physical activity according to their subjective feelings. The items measure students' sedentary time, where a larger score indicates a longer sedentary time. The revised Chinese version has overall and intragroup correlation coefficients between 0.76 and 0.88, hinting at its good retest reliability [22]. In this test, the internal consistency reliabilities of the scale were 0.732 (T1), 0.768 (T2), and 0.711 (T3).

(2) Mobile Phone and Other Electronic Product Addiction Inventory [23]: This scale was used to quantify mobile phone addiction in adolescents. This scale was revised by Deng et al. [21] from the "Problematic Smart

Phone Usage Scale" compiled by Meng et al. The description of "smart phone" was changed to "mobile phone and other electronic products" to measure the use of electronic products. The structural validity of this revised scale was verified. Deng et al. [21] obtained the following results from the group of adolescents in China: χ^2/df = 7.617, CFI = 0.946, GFI = 0.946, TLI = 0.928, RMSEA = 0.065, SRMR = 0.036, good fit, and Cronbach's α coefficient = 0.81. The scale has nine items and scores by "Yes" and "No", that is, 1 for "Yes" and 0 for "No". A higher score indicates more serious mobile phone and other EPA. A total score >5 is diagnosed as mobile phone and other EPA. In this test, the internal consistency reliabilities of the scale were 0.919 (T1), 0.891 (T2), and 0.933 (T3).

(3) Depression Subscale of Achenbach Self-rating Adolescent Behavior Scale [24]: This scale, originally compiled by Achenbach and revised by Chinese scholars Liu et al. [24], was used to determine D level. Achenbach Child Behavior Check List was compiled by American psychologists Achenbach and Edelbrock [21] in 1976, and repeatedly revised by Achenbach et al. [25,26]. It is the most commonly used tool for assessing children's behavioral problems and social abilities internationally. Particularly, Achenbach Self-rating Adolescent Behavior Scale, revised by Liu et al., is the most widely used for the group of adolescents in China. The scale covers eight items and uses the Likert four-point scoring method, ranging from 1 (never) to 4 (often). A higher score indicates more serious D. In this test, the internal consistency reliabilities of the scale were 0.949 (T1), 0.932 (T2), and 0.909 (T3).

Data analysis

SPSS 22.0 statistical software was used to analyze the valid data. After processing with reverse items, centralization, and calculation of relevant latent variable scores, a series of methods including descriptive statistics, independent sample *t*-tests, one-way ANOVA, and Pearson correlation were performed for analysis, where $p < 0.05$ is statistically significant. Two-way ANOVA was conducted with a repeated measurement factor to explore the differences in SB, EPA, and D among the participants of different genders and with dissimilar sedentary times. If the spherical symmetry assumption was not satisfied during the ANOVA, the Greenhouse Geisser method was used for correction. Given any interactive effect between time and gender factors, a separate effect analysis was further conducted. AMOS 23.0 software was used to build the model and carry out cross-lagged analysis, and the maximum likelihood method was used to test the fitting and adaptability of the model.

Results

Difference analysis

Table 1 presents the results of repeated measure ANOVA with time as the repeated measure variable and gender as the intergroup variable. The statistical results of SB show its main gender effect is not significant (F = 1.29, $p > 0.05$), whereas its time effect is significant (F = 5.98, $p = 0.001$); the interaction between gender and time is significant (F = 6.11, $p < 0.05$). The results of simple effect analysis show girls' SB increase sequentially over time, but this effect is not true for boys. The statistical results of EPA show its main gender effect is significant (F = 3.99, $p < 0.05$), and its time effect is significant (F = 7.13, $p < 0.001$); the interaction between gender and time is significant (F = 11.32, $p < 0.01$). The results of simple effect analysis show boys' EPA increase sequentially over time, but this effect is not true for girls. The statistical results of D show its main gender effect is significant (F = 4.19, $p < 0.05$), and its time effect is significant (F = 8.33, $p < 0.001$); the interaction between gender and time is not significant (F = 10.43, $p < 0.01$).

Correlation analysis

Table 2 shows the results of correlation analysis of variables. In the three measures, significant positive correlations were observed among SB, EPA, and D. At T1, sedentary time is significantly positively correlated with EPA and D, and EPA is positively correlated with D. At T2 and T3, pairwise positive correlations were noted among sedentary time, EPA, and D. Significant positive correlations were seen among T1, T2, and T3 in terms of sedentary time. Significant positive correlations were observed among T1, T2, and T3 in terms of EPA. Significant positive correlations were revealed among T1, T2, and T3 in terms of D.

Cross-lagged analysis

Cross-lagged model test was conducted using Amos 23.0 software to investigate the relationships among SB, EPA, and D. The fitting results of the model are good, with X^2/df = 2.13, GFI = 0.98, IFI = 0.97, CFI = 0.99, and AGFI = 0.97. Fig. 1 shows SB at T1 could significantly positively predict

TABLE 1

Difference analysis

Variable	Gender	T1	T1	T3	Effect between groups	Effect intragroup	Interaction
Sedentary behavior	Female	3.59 ± 1.22	3.79 ± 1.77	3.80 ± 2.07	F = 1.29	F = 5.98	F = 6.11
	Male	3.31 ± 1.19	3.41 ± 1.50	3.38 ± 1.95	$p > 0.05$	$p = 0.001$	$p = 0.001$
Electronic product addiction	Female	3.66 ± 3.38	4.10 ± 2.50	4.52 ± 2.37	F = 3.99	F = 7.13	F = 11.32
	Male	4.95 ± 3.49	5.62 ± 3.35	6.12 ± 2.78	$p < 0.05$	$p < 0.001$	$p < 0.01$
Depression	Female	2.44 ± 0.47	2.14 ± 0.63	2.38 ± 0.57	F = 4.19	F = 8.33	F = 10.43
	Male	2.12 ± 0.58	1.85 ± 0.59	2.12 ± 0.69	$p < 0.05$	$p < 0.001$	$p < 0.01$

TABLE 2

Correlation analysis of variables (r value, n = 604)

	ST-1	ST-2	ST-3	EPA-1	EPA-2	EPA-3	D-1	D-2	D-3
ST-1	1								
ST-2	0.104*	1							
ST-3	0.305**	0.145**	1						
EPA-1	0.549**	0.407**	0.411**	1					
EPA-2	0.325**	0.534**	0.331**	0.733**	1				
EPA-3	0.226**	0.306**	0.335**	0.462**	0.481**	1			
D-1	0.212**	0.225**	0.278**	0.432**	0.457**	0.606**	1		
D-2	0.212**	0.237**	0.266**	0.466**	0.461**	0.543**	0.753**	1	
D-3	0.115**	0.136**	0.255**	0.345**	0.351**	0.470**	0.610**	0.393**	1

Note: Sedentary time: ST. Electronic product addiction: EPA. Depression: D. * indicates $p < 0.05$, ** indicates $p < 0.01$.

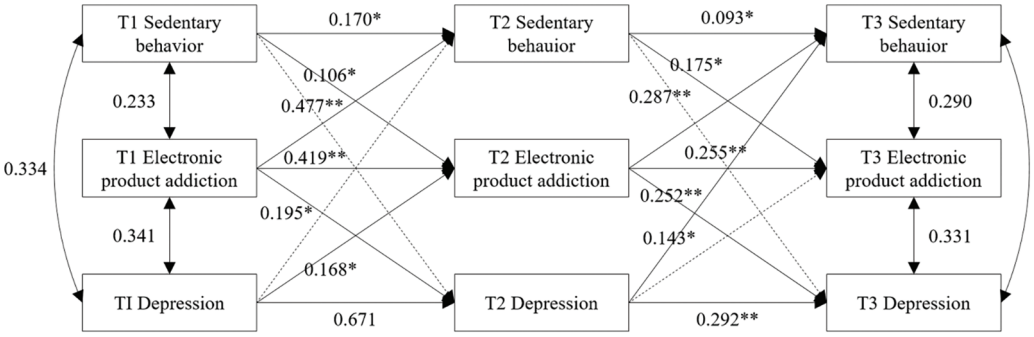

FIGURE 1. Cross-lagged analysis of sedentary behavior, electronic product addiction and depression.
Note: * indicates $p < 0.05$, ** indicates $p < 0.01$.

SB and EPA at T2, but it could not significantly predict D at T2; EPA at T1 could significantly positively predict SB, EPA, and D at T2; D at T1 could significantly predict D and EPA at T2, but it could not predict SB at T2; SB and physical activity level at T2 could significantly predict SB and EPA at T3, but it could not predict D at T3; EPA at T2 could significantly predict SB, EPA, and D at T3; D at T2 could significantly predict SB and D at T3, but it could not predict EPA at T3. In brief, first, SB could lead to addiction and D; second, EPA and D could also lead to SB; third, a certain mediating effect was seen in the prediction of D by electronic product addition, whether on the cross-section or on the timeline.

Discussion

Gender difference analysis of sedentary behavior, electronic product addiction and depression in adolescents

IPAQ-S was used in this paper for the three measures of adolescents' SB. The results show the time effect of SB is not significant, and no significant differences were observed among the three measures. This outcome indicates adolescents' SB is a stable, time-independent habitual lifestyle. However, significant gender differences were found in the three measures, with girls having significantly longer sedentary time than boys. This result is consistent with other similar findings [18,27]. However, Wang et al. [28] found in a study on the correlations among physical activity level, SB, and D symptoms in adolescents that no gender difference exists among adolescents in sedentary time after class. Its inconsistency with the investigation results of this study may be mainly caused by the selection of different measuring instruments. Adolescents aged 10–15 years old are at the stage of puberty. The rapid secretion of sex hormones leads to some differences between male and female students in physical strength, bone, and muscle content [29]. Therefore, a variance in physical activity level exists between male and female students. Moreover, according to gender theory, the differences between male and female students are not only derived from genetic factors but also related to gender identity [30]. Social culture generally holds that men should be strong and powerful, whereas women should be quiet and dignified. Such gender stereotypes lead to the difference between boys and girls in physical activity level.

After the three measures of EPA, the time effect of EPA is significant with an increasing trend, hinting at the persistent effect of EPA behavior. Boys have higher scores than girls in the three measures, with significant differences. This result is consistent with the those obtained by Dong et al. [31] and Li et al. [32]. Li et al. [32] found some differences between male and female students in the purpose of using mobile

phones. Girls mostly use mobile phones for watching videos and social interaction, whereas boys use mobile phones more for watching videos and playing games. Their dissimilar purposes may lead to the difference between male and female students in mobile phone addiction [33]. Because playing games is more non-interruptible than social interaction and watching videos and can bring a stronger sense of victory and defeat, it may lead to a higher level of mobile phone addiction in boys.

Depression Subscale of Achenbach Self-rating Adolescent Behavior Scale was used for the three measures of D in adolescents. The results of data analysis show the time effect of D is significant, with T1 and T3 significantly higher than T2. The results also reveal a gender difference in D, with girls higher than boys, which is consistent with previous research results [34,35]. Many studies found that the detection rate of D is significantly higher in women than in men [36]. This result may be related to the physiological development and social gender of men and women. Girls enter puberty earlier than boys, and the secretion of hormones not only affects individuals' physiological characteristics but also causes psychological distress such as emotional fluctuations [37]. Moreover, girls are more prone to D because they are more sensitive than boys and are more negative about life events [38]. Moreover, society is still dominated by the traditional gender view that men are in charge of earning money to support the family, whereas women are responsible for doing housework. Women are expected to have the same achievements as men in school and career and undertake more family affairs, thus facing greater pressure. This reason might explain why girls have more serious D than boys and highlights the necessity to treat students differently by gender during an epidemic to manage EPA better.

Correlation analysis of sedentary behavior, electronic product addiction and depression in adolescents

A correlation analysis was conducted on the results of the three measures of SB, EPA, and D in adolescents. The results show pairwise positive correlations among the three measures of SB, EPA, and D in adolescents with significant correlation levels. This finding indicates certain internal relationships exist among SB, EPA, and D in adolescents, which could be further studied longitudinally.

The significant correlation between adolescent SB and EPA has been confirmed by many studies [39,40]. On the one hand, SB is the inevitable result of EPA. The use of electronic products is often accompanied by fixed sitting, lying, and other positions. Given the high concentration of attention on the use of electronic products, the activity of other parts of the body is reduced, resulting in "bowing" and other special behaviors. On the other hand, SB also aggravates the use of electronic products. The scope and opportunities of individual activity have been greatly reduced with the development of science and technology, especially the implementation of various control measures after the outbreak of the epidemic. The lack of effective stimulation from physical activity inevitably leads to the shift of attention to the use of electronic products and other items. In addition, convenient, fast online operation greatly reduces the demand for physical activity but increases the time for rest.

SB greatly increases the risk of D in adolescents, which is consistent with the results reported by Martínez-López et al. [41] and Chen et al. [42]. On the one hand, SB leads to obesity, overweight, and other physical problems, and these physical problems can increase the risk of cardiovascular and cerebrovascular diseases, leading to an increased risk of D [43]. They can also cause inferiority complex and an increased risk of D. On the other hand, SB leads to the reduction of physical activity. Notably, activity can produce hormones such as dopamine, which is one of the protective factors of D [44]. Moreover, SB reduces interpersonal interaction in real life. The negative effect of the epidemic-dominated social environment further leads to the lack of sociality, resulting in D [45].

This paper found that EPA is correlated with D in adolescents, which is similar to the survey results of He et al. [46] and Tao et al. [47]. The main reason is as follows: Puberty is a key period of neural development, during which individuals are featured with strong plasticity, rapid development of attention and control ability, and susceptibility to disturbance from external factors [43]. Adolescents are highly sensitive to the information provided by digital media, networks, and electronic devices. Overuse may affect their nerves, resulting in emotional sensitivity. Furthermore, it may affect the activities of relevant brain areas in emotional processing and lead to the hyperactivity or inhibition of the control and reward systems, resulting in D [47].

Cross-lagged analysis of physical activity, sense of ego and sense of psychological consistency in adolescents

A cross-lagged model test was conducted using AMOS 23.0 on the relationships among the three measures of SB, EPA, and D. The results show relatively complex causal relationships among SB, EPA, and D in adolescents. Specifically, a causal relationship was observed between SB and EPA. Adolescents who often sit for a long time are more likely to have EPA, whereas adolescents addicted to electronic products are more likely to have SB. EPA at T1 could significantly predict D at T2, whereas EPA at T2 could significantly predict D at T3. This result indicates that EPA can significantly predict adolescent D and is an inducing factor of D. Moreover, SB leads to addiction and D. No matter on the cross-section or on the timeline, EPA could predict D with a certain mediating effect. SB could predict D and affect D through the mediating role of EPA. SB has an independent effect on adolescents' physical and mental health, either through physical and mental factors or through EPA. The results of cross-lagged analysis show SB and EPA are predictors of D, and a causal relationship exists between them. Moreover, SB could significantly positively predict D and indirectly predict D through the mediating role of EPA. This suggests that popularizing healthy lifestyles and fostering healthy behaviors among children, including reducing sedentary behavior, is a cost-effective health management strategy that can improve children's physical and mental health levels; at the same

time, the combination of reducing sedentary behavior and promoting physical activity, which may be a promising intervention strategy, can be incorporated into the design of electronic product addiction interventions.

Limitation

The limitation of this paper lies in the measurement of data at only three time points. In the future, the tracking interval can be extended to explore a more accurate change trend for each variable and the more stable relationships among the variables. Moreover, the interview method can be combined to probe deeper into the existing mechanism. The conclusions above highlight the need to pay attention to the use of electronic products by adolescents and increase their physical activity to reduce the incidence of D. Furthermore, they indirectly suggest that during an epidemic, in addition to the necessary epidemic control, relevant policies should be formulated to reduce adolescents' SB. In addition, the data on SB in this paper were collected from the participants' self-reports. Although the copies of the relevant survey questionnaire were filled in and collected collectively under the instruction and on-site guidance of the research team members, ensuring the objectivity and comprehensiveness of all data was still difficult. Future research on the measurement of SB should involve other more objective detection methods, especially the use of human energy consumption detectors such as Actigraphy accelerometer.

Conclusions

The current situation of and relationships among SB, EPA, and D were examined in this paper through a cross-lagged design. The results show boys have lower scores in SB and D than girls, but they have a higher score in EPA than girls, with significant gender differences. Significant positive correlations were observed among SB, EPA, and D. Specifically, SB and EPA are predictors of D. A causal relationship was noted between SB and EPA. Moreover, SB could significantly positively predict D and indirectly predict D through the mediating role of EPA.

Acknowledgement: Feng Sheng is the corresponding author. The author thanks all the team members for their committed participation in this study.

Funding Statement: This study was supported by Youth Fund of Humanities and Social Sciences Research Project of Education Ministry (22YJC890025).

Author Contributions: The authors confirm contribution to the paper as follows: study conception and design: Feng Sheng; data collection: Feng Sheng, Chen Kong and Chao Li; analysis and interpretation of results: Feng Sheng and Chen Kong; draft manuscript preparation: Feng Sheng and Chao Li. All authors reviewed the results and approved the final version of the manuscript.

Availability of Data and Materials: The data can be obtained on request.

Ethics Approval: This experiment was conducted in accordance with the Declaration of Helsinki and has been approved by the Ethics Committee. Consent has been obtained from all the participants involved in this experiment. All the experiment schemes have been approved by the designated institution and/or licensing committee (Ethics Committee of Qufu Normal University, China. No. 20211205).

Conflicts of Interest: The authors declare that they have no conflicts of interest to report regarding the present study.

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