Characteristics and Evolution of Adolescent Depressive Symptoms Across Different Mobile Phone Usage Durations: A Large-Sample Network Analysis

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Abstract

This study conducted a large-scale survey of 167,728 adolescents in Nanchong City using the Center for Epidemiologic Studies Depression Scale (CES-D), employing network analysis methods to investigate the characteristics and evolutionary patterns of depressive symptoms among adolescents under different mobile phone usage durations on rest days. The results indicate that longer mobile phone usage duration among adolescents is associated with more severe depressive symptoms; "sadness," "feelings of failure," "anhedonia," and "absence of well-being" exhibited high strength centrality among these depressive symptoms; under three conditions—never using mobile phones on rest days, using mobile phones on rest days but $ $3 hours per day, and using mobile phones on rest days but >3 hours per day—the global network strength, network structure, and network edges of depressive symptoms all showed varying degrees of differences; under conditions of identical mobile phone usage duration on rest days, the global network strength, network structure, and network edges of depressive symptoms also showed varying degrees of differences among adolescents of different genders. Based on the characteristics and evolutionary patterns of depressive symptoms under different mobile phone usage durations on rest days, this study innovatively proposed four evolution patterns of depressive symptoms, providing novel strategies for the prevention and control of adolescent depression.

Full Text

Preamble

Self-Check Report for Acta Psychologica Sinica
Please complete the following items and paste them on the first page of your

manuscript.

1. List up to three innovative contributions of this study in the form of "Research Highlights," with a total word count not exceeding 200 words.
Response:
1. This study innovatively investigates the characteristics and evolution patterns of depressive symptom networks among adolescents under different durations of mobile phone usage on rest days.
2. In the R-based network analysis, we innovatively calculated global efficiency (previous studies only computed network density; global efficiency is more complex to calculate and carries greater significance), thereby enhancing the interpretability of network analysis results.
3. Based on our findings, we innovatively propose four evolution patterns of depressive symptoms ("steady stepwise change," "slow then rapid," "gradual accumulation," and "fluctuating" patterns), providing novel strategies for adolescent depression prevention and control.

2. Have you published or submitted any articles using the same data as this study? If yes, please attach them for review.
Response: No.

3. What methods did you use to control or demonstrate that common method bias would not affect the validity of your conclusions? What measures were taken?
Response: We employed Harman's single-factor test. The results showed that the first factor explained 44.69% of the variance, below the international critical threshold of 50%, indicating no common method bias.

Podsakoff, P. M., & Organ, D. W. (1986). Self-reports in organizational research: Problems and prospects. Journal of management, 12(4), 531-544.

5. Please state the planned sample size and actual sample size. If they differ, explain why.
Response: This was a large-scale census survey. Data from 167,728 adolescents were included in the analysis, which is sufficient.

6. In hypothesis testing, if using Null Hypothesis Significance Testing (NHST), report exact p-values rather than intervals (report intervals only when $p < 0.001$, otherwise report exact p-values). Does your paper meet this requirement? If using Bayes factors, have you reported their sensitivity to prior distribution assumptions?
Response: Yes, our paper meets this requirement.

7. To ensure completeness of data reporting, if you excluded data in statistical analysis, did you report this in the text? What were the reasons? How would results change if these data were included? How were missing data handled? Did you delete individual items when using scales? Why? How would results change if these items were

included? Were there any measured items or variables not reported? Why? Please indicate their location in the paper.
Response: Questionnaires and scales were administered to 175,404 participants. Data from participants with missing demographic information or incomplete item responses were excluded. Ultimately, data from 167,728 participants were included in statistical analysis, yielding a valid response rate of 95.62%.

8. Are any experimental materials, scales, or questionnaires that have not undergone peer review attached at the end of the file? If not, explain why. If this article is published, are you willing to share these materials with other researchers?
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Response: This study has been approved by the Nanchong Physical and Mental Hospital Medical Ethics Committee (IRB No.: NCPP2022002).

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Characteristics and Evolution of Depressive Symptoms Among Adolescents Under Different Mobile Phone Usage Durations: A Large-Sample Network Analysis

Abstract

This study conducted a large-scale census survey of 167,728 adolescents in Nanchong City using the Center for Epidemiological Studies Depression Scale (CES-D) and employed network analysis to investigate the characteristics and evolution patterns of depressive symptoms under different durations of mobile phone usage on rest days. Results indicated that longer mobile phone usage was associated with more severe depressive symptoms. Among depressive symptoms, "sadness," "sense of failure," "lack of pleasure," and "lack of happiness" exhibited high strength centrality. Significant differences were observed in network global strength, structure, and edges across three conditions: no mobile phone use on rest days, usage $ $3 hours daily, and usage >3 hours daily. Additionally, significant differences in network global strength, structure, and edges emerged between genders under the same usage duration conditions. Based on these characteristics and evolution patterns, this study innovatively proposes four evolution modes of depressive symptoms, offering novel strategies for adolescent depression prevention and control.

Keywords: mobile phone usage duration, depressive symptoms, adolescents, network analysis
Classification Code: R395

Introduction

Mobile phones have become humanity's most common communication device. The 53rd Statistical Report on China's Internet Development shows that as of June 2023, China had 1.079 billion internet users, with those under 19 years accounting for 17.7%. Among Chinese internet users, 99.8% access the internet via mobile phones, with an average daily usage of 4.16 hours (CNNIC, 2024). Based on these figures, approximately 191 million Chinese adolescents use mobile phones to access the internet (1.079 billion × 17.7% × 99.8% 191 million). Previous research has found that mobile phone dependence adversely affects adolescent physical and mental health. For instance, mobile dependence positively correlates with sleep disorders among adolescents in the United States and Turkey (Nagata et al., 2023; Acikgoz et al., 2022), with depressive mood among Korean adolescents (Jeong et al., 2023), and with depressive symptoms among Chinese adolescents (Yang et al., 2023). However, concepts such as mobile phone dependence, mobile addiction, and problematic mobile phone use lack unified definitions and clear boundaries in academia (Zhu et al., 2023; Chen et al., 2023). Moreover, commonly used scales such as the Mobile Phone Dependence Questionnaire (MPIQ) (Raney et al., 2023), Mobile Phone Problem Use Scale (MPPUS) (Lopez-Fernandez et al., 2014), and Smartphone Addiction Scale (SAS) and its short version (SAS-SV) (Xiang et al., 2019; Zeng et

al., 2024) primarily assess subjective feelings about mobile phone use rather than actual usage duration. Consequently, despite the vast number of adolescent mobile phone users and the documented impact of improper use on their well-being, research on how usage duration specifically affects adolescent mental health remains limited.

Prolonged mobile phone usage has become a major public health issue among adolescents (Riesch et al., 2019). First, in August 2023, the Cyberspace Administration of China drafted the "Guidelines for the Construction of a Minor-Friendly Mode for Mobile Internet (Exposure Draft)," which proposed regulations on internet usage duration for minors (CAC, 2023). Second, China's "Regulations on the Protection of Minors in Cyberspace," implemented on January 1, 2024, stipulates in Articles 40 and 41 that teachers and guardians should guide minors in safe and reasonable internet use, monitor their online activities and related physical and psychological conditions, and arrange appropriate time for internet usage (State Council, 2023a). Thus, mobile phone usage duration has gradually become a core element of mobile phone regulation, making it a valuable entry point for safeguarding adolescent mental health.

Furthermore, research indicates that approximately 50% of mental disorders begin by age 14 (Colizzi et al., 2020), and the global trend of depression among adolescents has been rising in recent years, with suicide being the second leading cause of death in this population (Kessler et al., 2012). Depression is a common mental disorder characterized by persistent low mood, anhedonia, and negative cognition, which severely reduces quality of life and can lead to suicide in severe cases (Lim et al., 2018; Malhi & Mann, 2018; Feng & Liao, 2023). The pathogenesis of depression is extremely complex, influenced by biological, psychosocial, and cognitive-neurological factors (Shorey et al., 2022), making it difficult to understand its development from a single perspective. Recent research has found that multiple symptoms of depression are non-independent and non-interchangeable. Compared with traditional methods, structural and dynamic analysis of depressive symptom networks not only provides a more comprehensive and flexible explanation for the occurrence of depression but also offers quantifiable indicators for its changes (Zhang et al., 2023). Based on this, the present study used the Chinese version of the 20-item Center for Epidemiological Studies Depression Scale (CES-D) (Zhang et al., 2010), treating each of its 20 items as 20 distinct depressive symptoms. Through network analysis, each symptom was represented as a node in the network, with the thickness of edges between nodes representing the strength of associations between symptoms, thereby revealing the characteristics and evolution patterns of adolescent depressive symptoms under different mobile phone usage durations (Hirota et al., 2021).

Current research on the relationship between mobile phone usage duration and depressive symptoms among adolescents is scarce, and existing studies have several limitations: (1) Most previous studies have used small samples and failed to cover adolescents across all school-age groups (Meng et al., 2020; Qiu et al.,

2022). Large-sample studies not only better represent the entire adolescent population but also reduce random error and enhance result credibility. (2) Previous studies have not separated mobile phone usage on school days from rest days (Zhang et al., 2018; Zhang et al., 2022). Since adolescents have different schedules on school days and rest days, their mobile phone usage patterns may differ. Therefore, distinguishing between school days, rest days, and different durations can improve the precision of results when examining the relationship between depressive symptoms and mobile phone usage. (3) Previous studies have only examined network density without exploring global efficiency (Chen et al., 2023; Liang et al., 2020). While network density only reflects the sparsity of network connections, global efficiency can reflect the efficiency of information transmission within the network, which carries greater significance (Tian et al., 2020). Therefore, this study is the first to calculate and analyze global efficiency in depressive symptom network analysis using R, enhancing the interpretability of results.

In summary, this study employed network comparison analysis with a large sample to explore the characteristics and evolution patterns of adolescent depressive symptoms under different mobile phone usage durations. The study aims to achieve the following objectives: (1) By ranking network node strength centrality indicators, identify core depressive symptoms across different mobile phone usage durations and between genders, providing potential intervention targets for prevention and control; (2) By comparing depressive symptom networks across different mobile phone usage durations and genders in terms of global strength, network structure, edge differences, and node strength centrality, summarize the evolution patterns of depressive symptoms and propose refined coping strategies tailored to different symptom evolution characteristics; (3) Through comprehensive analysis of mobile phone usage duration on both school days and rest days, provide preliminary recommendations for regulating adolescent mobile phone usage duration.

2. Methods

2.1 Participants In May 2023, as part of the "Zhengxin" Health Engineering Project pilot in Nanchong City, Sichuan Provincial Department of Civil Affairs (the Nanchong "Zhengxin" Health Engineering Project), and following five rounds of expert review of questionnaires, testing procedures, assessor training, and data collection, this study—with assistance from the Nanchong Civil Affairs Bureau—conducted a census survey across all primary schools, junior high schools (regular and vocational), and senior high schools (regular and vocational) in Nanchong's eight administrative districts (Gaoping, Jialing, Langzhong, Nanbu, Yingshan, Yilong, Peng'an, and Xichong). Inclusion criteria were: (1) students with a unique digital identifier (UID) in the school registration system; (2) students in grades 4–6 of primary school, grades 1–3 of junior high school, or grades 1–3 of senior high school; (3) students and their parents or legal guardians who voluntarily participated and provided electronic

informed consent. A total of 175,404 eligible adolescent participants were identified. After distributing demographic questionnaires and the CES-D scale, data from participants with missing demographic information or incomplete item responses were excluded. Ultimately, data from 167,728 adolescent participants were included in statistical analysis, yielding a valid response rate of 95.62%. This study received formal approval from the Nanchong Physical and Mental Hospital Medical Ethics Committee (IRB No.: NCPP2022002).

2.2 Measures The Center for Epidemiological Studies Depression Scale (CES-D) was developed by Radloff in 1977 at the U.S. National Institute of Mental Health. The Chinese version of the CES-D is a reliable and valid self-report measure of depressive symptoms suitable for different age groups in China (Zhang et al., 2010) and has been used in numerous studies screening for depressive symptoms among Chinese adolescents (He et al., 2021; Tang et al., 2024). The scale comprises three dimensions: depressive mood, positive mood, and interpersonal relationships (Guarnaccia et al., 1989), with a total of 20 items. Items 4, 8, 12, and 16 are reverse-scored. Participants rate the frequency of symptoms over the past week on a 0–3 scale. The total score ranges from 0 to 60, with scores $ $16 indicating depressive symptoms and scores <16 indicating no depressive symptoms (Wang et al., 2023). In this survey, the scale's Cronbach's α coefficient was 0.942.

2.3 Statistical Analysis **Descriptive Statistics:** We used SPSS (Windows version 27.0) for descriptive statistics. With CES-D total score as the dependent variable and coded mobile phone usage duration as the independent variable ("never use" coded as 1, "$ $3 hours" coded as 2, ">3 hours" coded as 3), we conducted correlation analyses.

Network Analysis: We used R (version 4.3.2) and its packages to estimate and compare depressive symptom networks across different mobile phone usage durations and genders. Network estimation and analysis in R followed standard guidelines published by Epskamp and colleagues (Epskamp & Fried, 2018; Epskamp et al., 2018) and referenced similar studies (Chen et al., 2023; Liang et al., 2020; Li et al., 2022). Network structures were estimated using the estimateNetwork function with the EBICglasso method. Network density, the simplest property of a network graph, refers to the ratio of actual edges to maximum possible edges in the network, serving as an indicator of edge density. The calculation formula is [MATH_{FORMULA}]. All centrality indices in this study were standardized Z-scores. Based on calculated shortest paths, network global efficiency—a measure of information transmission efficiency in the network—was computed using the mean and upper.tri functions. The calculation formula is [MATH_{FORMULA}] (Tian et al., 2020). The bootnet package was used to estimate the accuracy and stability of network structure and centrality indices, with 1,000 bootstrap samples. The as.data.frame function extracted values for subsequent graphing. Network comparisons were performed using the Network Comparison Test (NCT) package, with permutation

tests set to 1,000 iterations, significance level at 0.05, and correction method set to BH correction. The averageLayout function was used for unified network layout to facilitate visual comparison (Chen et al., 2023).

3. Results

3.1 Demographic Characteristics of Adolescent Depression Prevalence

As shown in Table 1 , the prevalence of depressive symptoms was significantly higher among females and only children compared to males and non-only children, respectively. The prevalence was also significantly higher among senior high school students, those living in towns, and those from reconstituted families compared to primary school students, rural residents, and those from two-parent families. Higher educational level was associated with higher depression prevalence. Except for adolescents older than 18, older age was associated with higher depression prevalence.

Importantly, 40.13% of adolescents never used mobile phones on school days, whereas only 8.96% never used them on rest days, confirming that adolescent mobile phone usage patterns differ substantially between school days and rest days and should be studied separately. Moreover, regardless of whether on school days or rest days, longer mobile phone usage duration was associated with higher depression prevalence (see Table 1 and Supplementary Table 1 online).

Correlation analysis revealed that Spearman's correlation coefficient between rest day mobile phone usage duration and CES-D total score was 0.21 ($p < 0.001$), while the correlation between school day usage duration and CES-D score was 0.07 ($p < 0.001$). Although both were significantly correlated with depressive symptoms, the correlation on rest days was three times stronger than on school days. Therefore, subsequent network comparisons focused only on depressive symptoms under different mobile phone usage durations on rest days.

Additionally, the 20 items of the CES-D represent 20 distinct depressive symptoms. Participants' responses to the 20 CES-D items are shown in Table 2 .

3.2.1 Network Structure of Adolescent Depressive Symptoms Under Different Rest Day Mobile Phone Usage Durations The CES-D assesses 20 depressive symptoms, with C1, C2, C3, C5, C6, C7, C9, C10, C11, C13, C14, C17, C18, and C20 belonging to the depressive mood dimension; C4, C8, C12, and C16 belonging to the positive mood dimension; and C15 and C19 belonging to the interpersonal relationships dimension (Guarnaccia et al., 1989). These three dimensions are distinguished by three different colors in the network (see Figure 1 [Figure 1: see original paper]). Participants who never used mobile phones on rest days, used them $ $3 hours daily, or used them >3 hours daily are denoted as T1, T2, and T3, respectively. The corresponding depressive symptom network structures are shown in Figure 1, with network

densities of 157/190, 163/190, and 146/190, and global efficiencies of 0.07, 0.07, and 0.08, respectively. The strongest edge in the network was between C8-C9 ("hopelessness-failure"), followed by C15-C19 ("hostility-feeling disliked") (see Figure 1). The 95% confidence intervals for edge weights were relatively narrow, indicating accurate edge estimation.

3.2.2 Network Structure of Depressive Symptoms by Gender Under Same Rest Day Mobile Phone Usage Duration Under T1, T2, and T3 conditions, the network structures for female and male groups are shown in Supplementary Figure 1 online. Under T1, network densities were 150/190 for females and 147/190 for males, with global efficiency of 0.07 for both. Under T2, network densities were 156/190 for females and 170/190 for males, with global efficiency of 0.07 for both. Under T3, network densities were 147/190 for females and 151/190 for males, with global efficiency of 0.08 for both. The strongest edges remained C8-C9 ("hopelessness-failure") and C15-C19 ("hostility-feeling disliked"). The 95% confidence intervals for edge weights were relatively narrow, indicating accurate edge estimation.

3.3.1 Network Centrality of Adolescent Depressive Symptoms Under Different Rest Day Mobile Phone Usage Durations The most commonly used network centrality index is node strength centrality. Node strength centrality for depressive symptom networks under T1, T2, and T3 conditions is shown in Figure 2 [Figure 2: see original paper]. We selected symptoms ranking in the top 20% of strength centrality as core symptoms. Under T1, core symptoms were: C18 "sadness" (1.61), C9 "failure" (1.22), C16 "lack of pleasure" (1.17), and C6 "oppression" (1.12). Under T2, core symptoms were: C18 "sadness" (1.40), C6 "oppression" (1.27), C9 "failure" (1.17), and C16 "lack of pleasure" (1.16). Under T3, core symptoms were: C9 "failure" (1.35), C18 "sadness" (1.30), C6 "oppression" (1.23), and C12 "lack of happiness" (1.20).

Other centrality indices are provided in Supplementary Figure 2 online. Strength centrality stability coefficients were 0.75 under T1, T2, and T3 (Supplementary Figure 4 [Figure 4: see original paper]). Stability coefficients greater than 0.5 are generally considered acceptable, while those greater than 0.7 indicate high reliability and stability (Li et al., 2022).

3.3.2 Network Centrality of Depressive Symptoms by Gender Under Same Rest Day Mobile Phone Usage Duration Under the same rest day mobile phone usage duration, node strength centrality differed between genders, as shown in Figure 3 [Figure 3: see original paper]. Under T1, female core symptoms were: C18 "sadness" (1.70), C9 "failure" (1.16), C6 "oppression" (1.14), and C16 "lack of pleasure" (1.11). Male core symptoms were: C18 "sadness" (1.48), C9 "failure" (1.28), C16 "lack of pleasure" (1.24), and C6 "oppression" (1.03). Under T2, female core symptoms were: C18 "sadness" (1.38), C6 "oppression" (1.21), C16 "lack of pleasure" (1.15), and C9 "failure" (1.14). Male core symptoms were: C18 "sadness" (1.35), C6 "oppression" (1.31), C9 "failure"

(1.27), and C16 “lack of pleasure” (1.15). Under T3, female core symptoms were: C18 “sadness” (1.35), C6 “oppression” (1.30), C9 “failure” (1.29), and C16 “lack of pleasure” (1.13). Male core symptoms were: C9 “failure” (1.39), C18 “sadness” (1.23), C6 “oppression” (1.21), and C12 “lack of happiness” (1.19).

Other centrality indices are provided in Supplementary Figure 3 online. Strength centrality stability coefficients for both female and male groups were 0.75 under T1, T2, and T3 conditions (Supplementary Figure 4), indicating highly reliable and stable results.

3.4.1 Network Comparison of Adolescent Depressive Symptoms Under Different Rest Day Mobile Phone Usage Durations Global strength values for depressive symptom networks under T1, T2, and T3 conditions were 9.19, 9.20, and 9.35, respectively. Network comparison analysis and permutation tests further compared differences in global strength, network structure (see Table 3), edge differences (see Supplementary Table 2 online), and node strength centrality differences (see Supplementary Table 4) across T1, T2, and T3 conditions.

Results showed that T2 vs. T1 had no significant differences in network global strength ($p = 0.876$) or network edges, but showed significant differences in network structure ($p = 0.042$), with strength centrality significantly different for one node. T3 vs. T1 showed significant differences in network global strength ($p = 0.012$), network structure ($p < 0.001$), and network edges, with 32 edges showing significant differences and strength centrality significantly different for 8 nodes. T3 vs. T2 showed significant differences in network global strength ($p < 0.001$), network structure ($p < 0.001$), and network edges, with 19 edges showing significant differences and strength centrality significantly different for 10 nodes.

Further categorical analysis of these significantly different edges and nodes revealed different evolution patterns for different symptoms and edges. As shown in Figure 4(a), C11 “sleep disturbance” was significantly weakened across T1 vs. T2, T1 vs. T3, and T2 vs. T3 comparisons. As shown in Figure 4(b), symptoms C7 “fatigue,” C10 “fear,” C12 “lack of happiness,” and C14 “loneliness,” along with 13 edges, showed no significant differences in T1 vs. T2, but were significantly strengthened in T1 vs. T3 and T2 vs. T3 for C7, C10, and C12, while C14 was significantly weakened, with 13 edges significantly strengthened. As shown in Figure 4(c), symptoms C6 “oppression,” C15 “hostility,” and C19 “feeling disliked,” along with 19 edges, showed no significant differences in T1 vs. T2 and T2 vs. T3, but in T1 vs. T3, C6 and C19 were significantly strengthened, C15 was significantly weakened, and 19 edges were significantly strengthened. As shown in Figure 4(d), symptoms C2 “appetite loss,” C5 “concentration difficulty,” C8 “hopelessness,” C9 “failure,” and C13 “reduced speech,” along with 6 edges, showed no significant differences in T1 vs. T2 and T1 vs. T3, but in T2 vs. T3, C2, C5, C9, and C13 were significantly strengthened, while C8 was significantly weakened, and 6 edges were significantly strengthened.

3.4.2 Network Comparison of Depressive Symptoms by Gender Under Same Rest Day Mobile Phone Usage Duration Global strength values for female and male groups under T1, T2, and T3 conditions were: females 9.31, 9.26, and 9.46; males 8.96, 9.06, and 9.21. We compared differences in global strength, network structure (see Table 3), edge differences (see Supplementary Table 3 online), and node strength centrality differences (see Supplementary Table 4 online) between genders under the same mobile phone usage duration.

Results showed that under T1 conditions, there were no significant differences in network structure ($p = 0.058$) or network edges between female (F1) and male (M1) groups, but global strength differed significantly ($p = 0.003$), with strength centrality significantly different for one node. Under T2 and T3 conditions, there were significant differences in global strength ($p = 0.001$), network structure ($p = 0.001$), and network edges between female (F2, F3) and male (M2, M3) groups. Under T2, 25 edges and strength centrality of 8 nodes differed significantly. Under T3, 15 edges and strength centrality of 5 nodes differed significantly.

Further categorical analysis revealed different evolution patterns for significantly different edges and nodes. As shown in Figure 5 Figure 5: see original paper, C17 "crying" was significantly stronger in females than males across T1, T2, and T3 conditions. As shown in Figure 5(b), C1 "annoyance" and C11 "sleep disturbance," along with 11 edges, showed no gender differences under T1, but were significantly stronger in females under T2 and T3, with 11 edges also significantly stronger in females. As shown in Figure 5(c), symptoms C2 "appetite loss," C3 "distress," C7 "fatigue," C12 "lack of happiness," and C15 "hostility," along with 14 edges, showed no gender differences under T1 and T3, but under T2, C2, C3, C7, and C12 were significantly stronger in females, C15 was significantly stronger in males, and 14 edges were significantly stronger in females. As shown in Figure 5(d), C13 "reduced speech" and C14 "loneliness," along with 4 edges, showed no gender differences under T1 and T2, but under T3, C13 was significantly stronger in females, 4 edges were significantly stronger in females, and C14 was significantly stronger in males.

4. Discussion

4.1 Adolescent Depression Prevalence Increases with Rest Day Mobile Phone Usage Duration The prevalence of depressive symptoms among adolescents in Nanchong City, Sichuan Province, was 24.72% in this study, higher than the rate in Jinan City (10.6%) (Kang et al., 2023) but lower than the rate in Shandong Province (25.91%) (Wang et al., 2023). The prevalence among primary, junior high, and senior high school students was 12.73%, 27.77%, and 33.26%, respectively—lower than rates for mainland primary school students (17%) (Huang et al., 2022) and junior high school students (30%) (Zhang et al., 2022), but higher than the rate for mainland senior high school students (33%) (Yu et al., 2022). This suggests that adolescent depression in Nanchong City is at a moderately high level nationally, particularly among senior high school students, possibly due to intense college entrance examination pressure, war-

ranting enhanced prevention efforts. This study found that female adolescents had significantly higher depression prevalence than males, consistent with previous research (Romano et al., 2022; Tapia et al., 2007). We also found that only children in Nanchong had significantly higher depression prevalence than non-only children, contrasting with findings from Jinan where only children had lower prevalence, possibly due to different scales used (PHQ-9) (Kang et al., 2023). Reconstituted family adolescents showed significantly higher prevalence than two-parent family adolescents, consistent with Korean findings (Park & Lee, 2020), indicating that two-parent families are protective against depressive symptoms. Research also shows that higher family cohesion is associated with lower depression levels in primary school students, with psychological quality mediating this relationship (Liu et al., 2023), suggesting that promoting family functioning may be an effective approach to preventing or reducing adolescent depressive symptoms (Chi et al., 2020).

Importantly, this study found that adolescent depression prevalence increased significantly with daily mobile phone usage duration, with rest day usage having a greater impact than school day usage. Possible reasons include: (1) Prolonged mobile phone use may lead to information overload, subsequently causing depressive symptoms. Research has found that extensive social media use causes information overload, which can lead to internet addiction, reducing real-world social quality and causing isolation (Zhang, 2023). (2) Prolonged exposure to negative information on mobile phones may lead to negative cognition and subsequent depressive symptoms. Research found that among Canadian adolescents, more mobile phone calls co-rumination was associated with increased depressive symptoms (Battaglini et al., 2024). (3) Increased mobile phone usage reduces time for sleep and physical activity, which can cause depressive symptoms. Research shows that exercise can improve depressive symptoms (Blumenthal & Rozanski, 2023), and the combination of excessive screen-based sedentary time and short sleep duration is associated with increased depressive symptoms (Ra, 2023).

Furthermore, China's Law on the Protection of Minors explicitly states that minor students may not bring smartphones into classrooms without school permission, and those brought to school should be centrally managed (State Council, 2023b). Similarly, the United Kingdom, Australia, Sweden, and other countries have implemented school policies restricting daytime smartphone use (Wood et al., 2023). Given that more adolescents use mobile phones on rest days than school days, rest day usage duration shows stronger correlation with depressive symptoms, and rest day usage lacks legal and policy regulation, focusing on rest day mobile phone usage duration as a leverage point for adolescent depression prevention and control is particularly important.

4.2 Characteristics and Gender Differences in Adolescent Depressive Symptom Networks Under Different Rest Day Mobile Phone Usage Durations Core symptoms in pathological networks are expected to activate

other symptoms more strongly and are considered potential important intervention targets (Borsboom & Cramer, 2013; Borsboom, 2017). Core depressive symptoms differed across rest day mobile phone usage durations: (1) Regardless of whether daily usage exceeded 3 hours, C18 “sadness,” C6 “oppression,” and C9 “failure” were consistently core symptoms; (2) When usage exceeded 3 hours, C12 “lack of happiness” replaced C16 “lack of pleasure” as a core symptom; (3) Core symptoms comprised 75% from the depressive mood dimension, 25% from the positive mood dimension, and 0% from the interpersonal relationships dimension. This suggests that depressive mood has a greater impact on adolescent depressive symptoms than interpersonal relationships, possibly because adolescents’ primary task is academic rather than social, making depression caused by academic pressure more noteworthy. As no previous studies have used CES-D to assess depressive symptom networks among adolescents with different mobile phone usage durations, direct comparison is not possible. However, a study using the 20-item CES-D among adolescents in southern Brazil found that interleukin-6 was associated with appetite changes, sleep disturbance, low mood, and worthlessness, while C-reactive protein was associated with sleep disturbance, fatigue, appetite changes, and anhedonia (Manfro et al., 2022). This suggests that future research could combine biochemical marker detection with scale assessment for more precise detection of adolescent depressive symptoms.

Additionally, core depressive symptoms differed between genders: (1) With no mobile phone use or usage $ $3 hours, core symptoms were similar for females and males; (2) When usage exceeded 3 hours, the primary core symptom for females was C18 “sadness,” while for males it was C9 “failure”; (3) When usage exceeded 3 hours, C12 “lack of happiness” replaced C16 “lack of pleasure” as a core symptom in males, while C16 remained a core symptom in females. This indicates that adolescent depression prevention and control should also consider gender differences.

4.3.1 Evolution Patterns of Depressive Symptom Networks Our depressive symptom network analysis showed that as rest day mobile phone usage duration increased, global efficiency values under T1, T2, and T3 conditions were 0.07, 0.07, and 0.08, respectively, while global strength values were 9.19, 9.20, and 9.35. Increases in global efficiency and global strength indicate faster information transmission and disease deterioration (Robinaugh et al., 2020), particularly pronounced at the >3 hours usage threshold. According to the recently proposed dual-pathway hierarchical network model of depression, faster information transmission in our study implies overactivation of the bottom-up negative affective processing pathway and related “hot” brain network clusters (Feng & Liao, 2023). Additionally, network densities under T1, T2, and T3 were 157/190, 163/190, and 146/190, respectively, with trends not synchronized with global strength changes. This enhances interpretability and facilitates comprehensive network change assessment, as network density only reflects connection sparsity, not information transmission efficiency. This suggests that in future

network analysis research, assessing global efficiency may be more meaningful than assessing network density.

Further analysis of significantly different symptoms and edges in network comparisons across different rest day mobile phone usage durations revealed that different symptoms and edges may follow different evolution patterns. Based on these findings and the patterns summarized in Figure 4, we innovatively propose four evolution patterns, as shown in Figure 6 [Figure 6: see original paper]: (a) "steady stepwise change," (b) "slow then rapid," (c) "gradual accumulation," and (d) "fluctuating" patterns.

Specifically, Figure 4(a) shows that C11 "sleep disturbance" follows the "steady stepwise change" pattern in Figure 6(a), weakening significantly regardless of whether usage is within or exceeds 3 hours. Figure 4(b) shows that C7 "fatigue," C10 "fear," and C12 "lack of happiness" follow the "slow then rapid" pattern in Figure 6(b), strengthening slowly when usage is within 3 hours (non-significant differences) but surging when usage exceeds 3 hours, creating significant differences. These symptoms are characterized by strong concealment in early stages, easily overlooked, but rapid onset later, potentially causing serious consequences. Figure 4(c) shows that C6 "oppression" and C19 "feeling disliked" follow the "gradual accumulation" pattern in Figure 6(c), strengthening slowly when usage is within 3 hours (non-significant differences), with differences reaching significance through cumulative effects when usage exceeds 3 hours. These symptoms develop steadily, are relatively identifiable early on, have slower later onset, and are coupled with many strengthened edges, potentially triggering strong cascade effects. Targeting these symptoms for depression prevention and control may yield better outcomes. Figure 4(d) shows that C2 "appetite loss," C5 "concentration difficulty," C9 "failure," and C13 "reduced speech" follow the "fluctuating" pattern in Figure 6(d), easing slowly when usage is within 3 hours but rebounding and surging when usage exceeds 3 hours, reaching significance. These symptoms are characterized by misleading improvement in early stages, causing complacency, but rapid later onset leading to serious consequences. Therefore, the best prevention and control strategy for symptoms following "slow then rapid" or "fluctuating" patterns is to limit rest day mobile phone usage to within 3 hours.

4.3.2 Gender Differences in Depressive Symptom Network Evolution
Under T1, T2, and T3 conditions, global efficiency was equal for female and male groups at 0.07, 0.07, and 0.08, respectively, indicating that information transmission efficiency increased for both genders when usage exceeded 3 hours. However, global strength was higher for females than males across all three conditions, indicating that females had more severe depressive symptoms than males regardless of mobile phone usage.

Further categorical analysis of significantly different edges and nodes between female and male groups revealed that: Figure 5(a) shows C17 "crying" is a distinctive female symptom unaffected by usage duration. Figure 5(b) shows C1

"annoyance" and C11 "sleep disturbance" are typical gender differences affected by usage duration, requiring consistent attention to these symptoms in females during depression prevention and control. Figure 5(c) shows C2 "appetite loss," C3 "distress," C7 "fatigue," C12 "lack of happiness," and C15 "hostility" are early-stage gender differences when usage is within 3 hours, requiring early intervention for C2, C3, C7, and C12 in females and C15 in males. Figure 5(d) shows C13 "reduced speech" and C14 "loneliness" are later-stage gender differences when usage exceeds 3 hours, requiring later intervention for C13 in females and C14 in males. Thus, adolescent depression prevention and control should implement symptom-specific interventions based on gender differences across different mobile phone usage durations.

4.4 Study Limitations This study has several limitations: (1) The large sample size made comprehensive longitudinal tracking difficult; (2) Scale results are susceptible to participant subjectivity; (3) Mobile phone browsing content was not investigated. Future improvements could include: (1) Conducting small-sample longitudinal studies of adolescents screened with depressive symptoms; (2) Combining subjective scale reports with objective physiological indicators to improve precision, such as inflammatory protein concentrations (Manfro et al., 2022) or cognitive-neurological functional connectivity (e.g., right amygdala node centrality positively correlates with smartphone dependence in U.S. adolescents (Tymofiyeva et al., 2020), and intrinsic functional connectivity between left parahippocampal gyrus and right middle temporal gyrus moderates the relationship between problematic mobile phone use and depressive symptoms in Anhui university students (Zou et al., 2022)); (3) Including investigations of mobile phone usage purposes and browsing content to explore interactive effects of usage duration and content on adolescent depressive symptoms.

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Supplementary Materials

Supplementary Table 1 Comparison of depression prevalence rates across different mobile phone usage durations

Group	Depressive Symptoms n (%)	No Depressive Symptoms n (%)	^{2}	p
T1 (Never use on school days)	15360 (22.82)	51949 (77.18)	75.809	<0.001
T2 ($ 3*hoursonschooldays*)|22884(24.70)|69760(75.30)||||*T*1(*Neveruseonschooldays*)|15360(22.82)|51949(77.18)|1	21037 (20.22)	83004 (79.78)	4628.605	<0.001
0.001||*T*3(> 3*hoursonschooldays*)|3231(41.56)|4544(58.44)||||*T*2(3*hoursonschooldays*)|22884(24.70)|69760(75.30)|1059.016				
0.001||*T*3(> 3*hoursonschooldays*)|3231(41.56)|4544(58.44)||||*T*1(*Neveruseonrestdays*)|2684(17.86)|12342(82.14)|45.743| <				
0.001||*T*2(3*hoursonrestdays*)|21037(20.22)|83004(79.78)||||*T*1(*Neveruseonrestdays*)|2684(17.86)|12342(82.14				
0.001||*T*3(> 3*hoursonrestdays*)|17754(36.49)|30907(63.51)||||*T*2($3 hours on rest days)				
T3 (>3 hours on rest days)	17754 (36.49)	30907 (63.51)		

Supplementary Figure 1 Network structures of depressive symptoms in different gender groups: (a) Never use mobile phone on rest days, (b) Use mobile

phone $ $3 hours daily on rest days, (c) Use mobile phone >3 hours daily on rest days

Supplementary Figure 2 (a) Betweenness centrality and (b) Closeness centrality of depressive symptom networks under different rest day mobile phone usage durations

Supplementary Figure 3 Node betweenness and closeness centrality of depressive symptom networks in different gender groups

Supplementary Figure 4 Results of subset bootstrap procedures: (a) Under different rest day mobile phone usage durations, (b) Under T1 condition in different gender groups, (c) Under T2 condition in different gender groups, (d) Under T3 condition in different gender groups

Supplementary Table 2 Comparison of edge differences in depressive symptom networks under different rest day mobile phone usage durations

Comparison	Edge Differences (32 edges)	Edge Differences (19 edges)
T2 vs. T1	C2-C5, C6-C10, C7-C10, C9-C14, C2-C17, C13-C17, C18-C20, C2-C4, C6-C8, C9-C8, C6-C12, C18-C12, C6-C19, C15-C19, C9-C10, C17-C20, C7-C15, C18-C15, C4-C19, C9-C4, C16-C15, C11-C14, C14-C15, C13-C12, C3-C15, C6-C7, C5-C4, C20-C16, C5-C13, C10-C18, C20-C8, C17-C15, C1-C10, C7-C13, C17-C12, C10-C20, C2-C20, C8-C19	

Supplementary Table 3 Comparison of edge differences in depressive symptom networks between gender groups

Comparison	Edge Differences (25 edges)	Edge Differences (15 edges)
F1 vs. M1	C5-C6, C2-C11, C6-C17, C11-C17, C13-C17, C14-C18, C17-C18, C17-C20, C10-C8, C13-C8, C1-C12, C11-C12, C17-C15, C15-C19, C8-C16, C6-C12, C1-C17, C5-C8, C20-C16, C12-C19, C1-C5, C9-C14, C9-C20, C11-C4, C1-C4, C10-C12, C6-C10, C6-C18, C6-C4	

Supplementary Table 4 Comparison of node strength centrality in depressive symptom networks

[Table content preserved with statistical comparisons]

Center for Epidemiological Studies Depression Scale (CES-D)

Questionnaire Instructions

The Center for Epidemiological Studies Depression Scale (CES-D), revised by Zhang Jie et al., consists of 20 items across three dimensions: depressive mood, positive mood, and interpersonal relationships. Items are rated on a 0-3 scale: 0 = rarely or none of the time (less than 1 day), 1 = some or a little of the time (1-2 days), 2 = occasionally or a moderate amount of time (3-4 days), 3 = most or all of the time (5-7 days). Total score ranges from 0-60, with scores $ $16 indicating depressive symptoms and scores <16 indicating no depressive symptoms. The scale is suitable for depression screening in general populations. Reverse-scored items: 4, 8, 12, 16.

Applicable population: General population rather than patients, as it assesses depressive mood rather than the full depressive syndrome.

Questionnaire Items

The following statements describe feelings you may have experienced. Please indicate how often you have felt this way during the past week.

Item	Rarely or none of the time (less than 1 day)	Some or a little of the time (1-2 days)	Occasionally or a moderate amount of time (3-4 days)	Most or all of the time (5-7 days)
1. I was bothered by things that usually don't bother me				
2. I did not feel like eating; my appetite was poor				

Item	Rarely or none of the time (less than 1 day)	Some or a little of the time (1-2 days)	Occasionally or a moderate amount of time (3-4 days)	Most or all of the time (5-7 days)
3. I felt that I could not shake off the blues even with help from my family or friends				
4. I felt that I was just as good as other people				

Item	Rarely or none of the time (less than 1 day)	Some or a little of the time (1-2 days)	Occasionally or a moderate amount of time (3-4 days)	Most or all of the time (5-7 days)
5. I had trou- ble keep- ing my mind on what I was do- ing				
6. I felt de- pressed				
7. I felt that ev- ery- thing I did was an ef- fort				

Item	Rarely or none of the time (less than 1 day)	Some or a little of the time (1-2 days)	Occasionally or a moderate amount of time (3-4 days)	Most or all of the time (5-7 days)
8. I felt hope-ful about the fu-ture				
9. I thought my life had been a fail-ure				
10. I felt fear-ful				
11. My sleep was rest-less				
12. I was happy				
13. I talked less than usual				

Item	Rarely or none of the time (less than 1 day)	Some or a little of the time (1-2 days)	Occasionally or a moderate amount of time (3-4 days)	Most or all of the time (5-7 days)
14. I felt lonely				
15. People were unfriendly				
16. I enjoyed life				
17. I had crying spells				
18. I felt sad				
19. I felt that people disliked me				
20. I could not get “going”				