

Sleep Problems and Internet Addiction Symptom Co-occurrence in Adolescents: A Cross-Lagged Panel Network Analysis

Lili Liu

Northwest Normal University

Shuang Li

202532061012@mail.bnu.edu.cn

Beijing Normal University

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Abstract

Background

Internet addiction and sleep problems frequently co-occur during adolescence, yet most evidence remains cross-sectional or based on total scores. Such designs obscure which specific symptoms transmit risk across domains over time.

Objective

This study used a cross-lagged panel network approach to identify symptom-level temporal pathways between Internet addiction and sleep problems among Chinese adolescents.

Methods

A two-wave school-based survey was conducted with 1,156 adolescents aged 12 to 18 years. Internet addiction symptoms and sleep-problem components were assessed in September 2025 and January 2026. Regularized cross-lagged panel networks were estimated with and without autoregressive paths. Expected influence, bridge expected influence, bootstrap difference tests, and sensitivity analyses were used to evaluate temporal importance and robustness.

Results

The non-autoregressive network retained 273 of 650 possible directed edges, most of which were positive. Cross-domain connectivity was markedly asymmetric: sleep problems predicted subsequent Internet addiction symptoms more strongly than Internet addiction predicted later sleep problems. Daytime dysfunction and poor sleep quality were the most influential bridge symptoms from sleep to Internet addiction. Within the Internet addiction domain, neglecting household or academic responsibilities and attempts to reduce Internet use were prominent temporal drivers, whereas hiding Internet use and using the Internet to relieve dysphoric mood were important receiving symptoms.

Conclusions

Adolescent Internet addiction and sleep problems appear to form a directional symptom system in which daytime impairment and perceived sleep quality play a key role in transmitting future Internet-related problems. Prevention efforts may benefit from targeting sleep functioning and self-regulation before Internet addiction symptoms become more consolidated.

Introduction

Adolescence is a developmental period in which digital media use, sleep regulation, emotional adjustment, and academic demands become tightly intertwined. In China, the scale of youth Internet exposure continues to expand, providing unprecedented opportunities for learning and connection while also increasing the public-health relevance of problematic Internet use (China Internet Network Information Center, 2026). Contemporary diagnostic and conceptual frameworks emphasize that problematic online behavior is best understood not merely by time online, but by impaired control, functional impairment, and persistence despite negative consequences (Brand et al., 2025a).

Sleep health is another central developmental concern. Adolescents are biologically inclined toward later sleep timing, but school schedules and intensive evening screen exposure often compress sleep duration and degrade sleep quality. Recent reviews show that sleep disturbance during adolescence is associated with poorer emotional regulation, reduced cognitive control, and heightened vulnerability to mental-health symptoms (Campbell et al., 2024). Evidence from youth samples further suggests that sleep problems and digital-media behaviors are reciprocally related, although the direction and symptom-specific mechanisms remain incompletely understood (Choong et al., 2025).

A growing body of empirical work has documented associations between problematic Internet use and sleep disturbance. In adolescent and young-adult samples, greater problematic Internet use has been linked to poorer subjective sleep quality, shorter sleep duration, greater daytime dysfunction, and higher psychological distress (Acharya et al., 2025). Studies in clinical and community samples also suggest that Internet addiction is embedded within broader systems of anxiety, depression, impulsivity, and self-regulatory difficulties (Bozkurt et al., 2024).

However, total-score approaches can hide clinically meaningful heterogeneity. Two adolescents with identical Internet addiction scores may differ substantially: one may stay online longer than intended, another may conceal Internet use, and another may use the Internet to escape negative affect. Sleep problems are equally multidimensional, comprising perceived quality, latency, duration, efficiency, disturbance, medication use, and daytime dysfunction. Network approaches are therefore useful because they treat symptoms or components as interacting elements rather than interchangeable indicators of a single latent burden (Briganti et al., 2024).

Cross-sectional network models have begun to clarify links between digital behavior and adolescent psychopathology, but they cannot distinguish temporal prediction from contemporaneous co-occurrence. Cross-lagged panel network models address this limitation by estimating directed symptom-to-symptom associations across measurement occasions while controlling for all other symptoms in the system. This framework is particularly suitable for identifying symptoms that act as temporal drivers, symptoms that receive influence, and bridge symptoms that connect two clinical domains over time (Schumacher et al., 2024).

The theoretical framework of the present study integrates symptom-network theory, compensatory Internet use theory, and the Interaction of Person-Affect-Cognition-Execution (I-PACE) model. Symptom-network theory proposes that psychological problems are maintained by direct relations among

observable symptoms; thus, sleep components and Internet addiction symptoms can be conceptualized as nodes in a dynamic system rather than as passive indicators of two separate latent disorders (Wysocki et al., 2025). Within this system, sleep disturbance may first generate fatigue, negative affect, and daytime dysfunction. Compensatory Internet use theory further suggests that adolescents may turn to online activities to compensate for tiredness, dysphoria, loneliness, or reduced offline functioning. These compensatory motives may then activate the affective, cognitive, and executive-control processes emphasized in the I-PACE model, including mood modification, attentional bias toward online rewards, impaired inhibitory control, and difficulty disengaging from Internet use (Brand et al., 2025b).

Accordingly, the current study assumes a recursive pathway: sleep disturbance may lead to fatigue, negative affect, and daytime dysfunction; these experiences may promote compensatory Internet use; repeated compensatory use may strengthen I-PACE-related affective, cognitive, and executive-control processes; and these processes may contribute to problematic Internet use. Problematic Internet use may then feed back into sleep through prolonged nighttime use, difficulty disengaging, bedtime displacement, and further sleep disturbance. This framework is consistent with cross-lagged network evidence showing that adolescents' online behaviors and contextual regulation processes influence one another over time (Tong et al., 2024), as well as longitudinal evidence that compulsive Internet use is shaped by prior regulatory and family processes while also eliciting subsequent environmental responses (Akungu et al., 2023). Therefore, sleep problems and problematic Internet use may form a mutually reinforcing system, and bridge symptoms such as daytime dysfunction may be crucial upstream points in this cycle.

Recent longitudinal evidence indicates that adolescent problematic Internet use can precede later psychological and sleep-related difficulties, but sleep problems may also forecast intensification of problematic Internet behaviors. For example, longitudinal research in adolescents has linked problematic Internet use to later emotional symptoms and functional impairment (Khan et al., 2024). Other work suggests that sleep disturbance can compromise executive control and increase reliance on online activities for mood regulation, creating conditions under which problematic use may escalate (Dibben et al., 2023).

The symptom-level bridge perspective is also clinically important. If particular sleep components, such as daytime dysfunction or subjective sleep quality, predict multiple later Internet addiction symptoms, then sleep-focused interventions may have broad downstream benefits. Conversely, if certain Internet addiction symptoms forecast future sleep problems, prevention may need to prioritize online self-regulation. Recent network studies of digital-media behaviors support the value of identifying bridge symptoms for targeted prevention, rather than treating broad diagnostic categories as uniform entities (Gou et al., 2024).

The present study therefore used a two-wave cross-lagged panel network to examine temporal symptom-level associations between Internet addiction and sleep problems among Chinese adolescents. We aimed to identify the strongest autoregressive pathways, characterize cross-domain

directions between sleep and Internet addiction, determine central and bridge symptoms, and evaluate the stability and robustness of these findings. Based on recent longitudinal and network research, we expected stronger temporal influence from sleep problems to later Internet addiction symptoms than in the reverse direction, particularly for daytime dysfunction and poor sleep quality (Jiang et al., 2025).

Methods

Participants and Procedure

Participants were recruited from middle and high schools in Huizhou, China. Two assessments were conducted approximately four months apart, in September 2025 and January 2026. After excluding invalid responses and cases without usable matched data, the final analytic sample included 1,156 adolescents aged 12 to 18 years. Among them, 543 were boys (46.97%) and 613 were girls (53.03%). The study was administered by trained research staff in classroom settings. Participation was voluntary, responses were anonymous at the analytic stage, and students were informed that they could withdraw at any time.

Measures

Internet addiction symptoms were assessed using the Chinese version of Young's 20-item Internet Addiction Test (IAT). The original IAT was developed by Young (1998) to assess the severity of problematic and compulsive Internet use. The scale assesses difficulties related to impaired control, excessive or prolonged Internet use, interference with academic and interpersonal functioning, concealment of Internet use, and use of the Internet for mood regulation. The Chinese version has demonstrated satisfactory psychometric properties in Chinese adolescent samples. In particular, Lai et al. (2013) evaluated the IAT among 844 Hong Kong Chinese adolescents and reported strong internal consistency as well as satisfactory convergent and concurrent validity, supporting its use for assessing Internet addiction symptoms in Chinese adolescents. In the present study, each of the 20 IAT items was treated as a separate network node rather than being aggregated into a total score. This item-level approach was adopted to preserve heterogeneity across specific manifestations of Internet addiction and to identify symptoms with distinct prospective roles within the longitudinal network.

Sleep problems were assessed using the Chinese version of the Pittsburgh Sleep Quality Index (PSQI). The original PSQI was developed by Buysse et al. (1989) to assess subjective sleep quality and sleep disturbances over the preceding month. The scale was subsequently translated and adapted for use in Chinese populations, and its reliability and validity have been supported in Chinese student samples (Zheng et al., 2016). The PSQI comprises seven components: subjective sleep quality, sleep latency, sleep duration, habitual sleep efficiency, sleep disturbance, use of sleep medication, and daytime dysfunction, with higher scores indicating more severe sleep problems. In the present study, the seven component scores were treated as separate sleep-network nodes.

Statistical Analysis

Descriptive statistics were calculated for the total sample and separately by sex, age group, and grade. Sex and age-group differences were examined using independent-samples *t* tests, whereas grade differences were examined using one-way analysis of variance. Age was categorized into 12–15 and 16–18 years to provide interpretable developmental strata. Effect sizes were reported as Cohen's *d* for independent-samples *t* tests and eta squared (η^2) for analyses of variance.

Temporal symptom-level associations between Internet addiction and sleep problems were examined using cross-lagged panel network analysis. This approach estimates prospective relationships among individual symptoms or components across measurement occasions while simultaneously accounting for the broader symptom system (Rhemtulla et al., 2022). It has also been successfully applied in large youth longitudinal datasets to identify unique prospective symptom-to-symptom relationships over time (Funkhouser et al., 2021). Each Time 2 node was regressed on all Time 1 Internet addiction and sleep nodes using regularized regression. Autoregressive and cross-lagged pathways were estimated to characterize temporal stability and prospective cross-symptom associations. Out-expected influence and in-expected influence were calculated to identify symptoms that predominantly exerted or received temporal influence, and bridge expected influence was used to identify nodes connecting the Internet addiction and sleep-problem communities. Network accuracy and stability were examined using bootstrap procedures. Stability coefficients were calculated for in-expected influence, out-expected influence, and bridge expected influence, and bootstrap difference tests were conducted to compare bridge influence across nodes. Sensitivity analyses were additionally performed to examine the robustness of the principal network findings.

Results

Descriptive Statistics and Demographic Differences

As shown in Table 1, the means and standard deviations for all items related to Internet addiction and sleep problems were calculated at both time points. At T1, the mean total score for Internet addiction was 35.04 (SD = 12.87), and the mean total score for sleep problems was 9.67 (SD = 3.54). At T2, the corresponding scores were 37.89 (SD = 13.90) and 9.11 (SD = 2.65), respectively. These results indicate that Internet addiction symptoms showed an overall increase across the two waves, whereas the total level of sleep problems showed a slight decrease.

Table 1
Abbreviation, means, and standard deviations of each variable in the present network at two time points

Items	Abbreviation	T1 M (SD)	T2 M (SD)
Symptoms of IAT			
Stay online longer than intended	IAT-1	2.22 (1.11)	2.18 (1.01)
Neglect responsibilities	IAT-2	1.99 (1.09)	2.02 (1.02)
Prefer Internet to intimacy	IAT-3	1.77 (0.99)	1.76 (1.03)
Form new online relationships	IAT-4	1.96 (1.11)	1.99 (1.09)
Others complain about time online	IAT-5	2.45 (1.28)	2.45 (1.19)
Schoolwork affected by Internet use	IAT-6	1.80 (0.99)	1.94 (0.97)
Check messages before other tasks	IAT-7	1.35 (0.74)	1.52 (0.87)
Daily life affected by Internet use	IAT-8	1.37 (0.71)	1.50 (0.83)
Concern about online privacy being known	IAT-9	2.02 (1.21)	2.21 (1.20)
Use Internet to relieve negative mood	IAT-10	2.17 (1.28)	2.45 (1.29)
Anticipate next online session	IAT-11	1.98 (1.16)	2.28 (1.15)
Feel empty or bored without Internet	IAT-12	1.70 (1.06)	1.86 (1.05)
Snap when interrupted online	IAT-13	1.49 (0.87)	1.63 (0.89)
Lose sleep due to late-night Internet use	IAT-14	1.49 (0.89)	1.73 (1.03)
Think about online activities offline	IAT-15	1.82 (1.04)	2.06 (1.08)
Say just a few more minutes	IAT-16	1.79 (1.06)	2.00 (1.05)
Fail to reduce Internet use	IAT-17	1.63 (0.97)	1.77 (0.99)
Hide time spent online	IAT-18	1.50 (0.91)	1.58 (0.90)
Prefer Internet to going out with friends	IAT-19	1.37 (0.78)	1.51 (0.89)
Irritable when unable to access Internet	IAT-20	1.31 (0.73)	1.45 (0.83)
Components of PSQI			
Subjective sleep quality	PSQI-1	1.04 (0.68)	1.15 (0.50)
Sleep latency	PSQI-2	0.43 (1.05)	1.42 (1.46)
Sleep duration	PSQI-3	1.27 (1.48)	0.00 (0.00)
Note. SD = standard deviation; IAT = Internet Addiction Test; PSQI = Pittsburgh Sleep Quality Index.			

Items	Abbreviation	T1 M (SD)	T2 M (SD)
Symptoms of IAT			
Sleep efficiency	PSQI-4	1.89 (1.45)	1.24 (1.48)
Sleep disturbance	PSQI-5	1.84 (0.55)	1.89 (0.58)
Use of sleep medication	PSQI-6	1.70 (0.69)	1.72 (0.70)
Daytime dysfunction	PSQI-7	1.65 (0.69)	1.69 (0.72)
Note. SD = standard deviation; IAT = Internet Addiction Test; PSQI = Pittsburgh Sleep Quality Index.			

As shown in Table 2, girls reported higher sleep-problem scores than boys at both waves (T1: $t = -3.73$, $p < 0.001$, $d = -0.28$; T2: $t = -4.93$, $p < 0.001$, $d = -0.29$), whereas sex differences in Internet addiction were not statistically significant (T1: $t = -0.20$, $p = 0.838$, $d = -0.01$; T2: $t = -1.20$, $p = 0.232$, $d = -0.07$). Older adolescents reported higher Internet addiction scores at both waves (T1: $t = -2.91$, $p = 0.004$, $d = -0.19$; T2: $t = -2.25$, $p = 0.025$, $d = -0.14$), but sleep-problem scores did not differ meaningfully by age group. Grade differences were evident for Internet addiction at T1 ($F = 66.84$, $p < .001$, $\eta^2 = 0.148$) and T2 ($F = 51.93$, $p < 0.001$, $\eta^2 = 0.119$), and for T1 sleep problems ($F = 5.93$, $p < 0.001$, $\eta^2 = 0.024$).

Table 2
Demographic descriptive statistics and group-difference tests

Variable	Group	n (%)	IAT T1	PSQI T1	IAT T2	PSQI T2	Difference tests
Sex	Boys	543 (46.97)	34.96 ± 12.67	9.52 ± 2.04	37.3 ± 14.52	8.70 ± 2.56	IAT T1: t = -0.20, d = -0.01 PSQI T1: t = -3.73 ^{***} , d = -0.28
	Girls	613 (53.03)	35.11 ± 13.05	10.09 ± 2.12	38.35 ± 13.32	9.46 ± 2.69	IAT T2: t = -1.20, d = -0.07 PSQI T2: t = -4.93 ^{***} , d = -0.29
Age	12–15 years	770 (66.61)	34.25 ± 12.57	9.81 ± 2.09	37.24 ± 13.79	9.18 ± 2.63	IAT T1: t = -2.91 ^{**} ;
	16–18 years	386 (33.39)	36.64 ± 13.33	9.81 ± 2.11	39.21 ± 14.06	8.94 ± 2.70	IAT T2: t = -2.25 [*] ; PSQI T1/T2: ns
Grade	Grade 7	330 (28.55)	27.55 ± 9.49	9.35 ± 2.04	30.89 ± 10.74	9.00 ± 2.43	IAT T1: F = 66.84 ^{***} , η^2 = 0.148
	Grade 8	349 (30.19)	36.05 ± 13.62	10.01 ± 2.28	38.13 ± 12.80	9.38 ± 2.79	PSQI T1: F = 5.93 ^{***} , η^2 = 0.024
	Grade 10	256 (22.15)	39.65 ± 11.85	10.10 ± 2.09	42.82 ± 15.34	8.97 ± 2.73	IAT T2: F = 51.93 ^{***} , η^2 = 0.119
	Grade 11	221 (19.12)	39.30 ± 12.23	9.95 ± 1.88	42.23 ± 13.74	9.00 ± 2.65	PSQI T2: F = 1.75, η^2 = 0.005

Note. IAT = Internet Addiction Test; PSQI = Pittsburgh Sleep Quality Index; *P < 0.05, **P < 0.01, ***P < 0.001; ns = not significant.

Full Cross-Lagged Network Including Autoregressive Paths

As shown in Fig. 1, the full cross-lagged network retained 296 nonzero directed paths. The strongest autoregressive paths were observed for sleep medication (PSQI-6 to PSQI-6; β = 0.406), Internet-related academic or occupational performance problems (IAT-4 to IAT-4; β = 0.368), staying online longer than intended (IAT-14 to IAT-14; β = 0.357), unsuccessful attempts to reduce Internet use (IAT-17 to IAT-17; β = 0.336), defensive reactions when questioned about Internet use (IAT-5 to IAT-5; β = 0.322), and blocking out disturbing thoughts with Internet use (IAT-10 to IAT-10; β = 0.321). These results indicate substantial symptom persistence across the four-month interval.

Non-Autoregressive Symptom-to-Symptom Network

As shown in Fig. 2 and Supplementary Table S1, after autoregressive paths were removed, 273 of 650 possible directed edges remained, including 255 positive and 18 negative edges. The strongest non-autoregressive paths were IAT-19 to IAT-3 ($\beta = 0.196$), PSQI-7 to IAT-10 ($\beta = 0.176$), PSQI-6 to PSQI-7 ($\beta = 0.163$), IAT-6 to IAT-2 ($\beta = 0.163$), PSQI-5 to IAT-9 ($\beta = 0.158$), IAT-2 to IAT-16 ($\beta = 0.140$), IAT-2 to IAT-14 ($\beta = 0.124$), and IAT-14 to IAT-10 ($\beta = 0.120$).

Cross-domain prediction was asymmetric in the non-autoregressive network (Fig. 2; Supplementary Table S1). Sleep-problem nodes predicted later Internet addiction symptoms through 66 directed paths with a total absolute weight of 2.217, whereas Internet addiction symptoms predicted later sleep-problem nodes through 22 paths with a total absolute weight of 0.111. The strongest sleep-to-Internet paths were daytime dysfunction to Internet use as a way of blocking out disturbing thoughts (PSQI-7 to IAT-10; $\beta = 0.176$), sleep disturbance to concealing time online (PSQI-5 to IAT-9; $\beta = 0.158$), daytime dysfunction to sleep loss due to late-night Internet use (PSQI-7 to IAT-6; $\beta = 0.110$), and daytime dysfunction to snapping or acting annoyed when interrupted online (PSQI-7 to IAT-13; $\beta = 0.089$).

By contrast, the strongest Internet-to-sleep paths were smaller and less consistent (Fig. 2; Supplementary Table S1). Neglecting household or academic responsibilities predicted lower subsequent sleep latency (IAT-6 to PSQI-2; $\beta = -0.077$), and academic or occupational performance problems predicted lower subsequent sleep latency (IAT-4 to PSQI-2; $\beta = -0.064$). Smaller positive pathways linked preoccupation with the Internet and difficulty reducing Internet use to later daytime dysfunction.

Centrality and Bridge Expected Influence

As shown in Fig. 3, out-expected influence identified symptoms that most strongly predicted the future symptom system. The highest out-expected influence values were observed for IAT-2 (1.489), PSQI-7 (1.286), PSQI-6 (0.968), IAT-6 (0.822), IAT-18 (0.642), PSQI-5 (0.598), IAT-20 (0.588), IAT-14 (0.482), IAT-17 (0.465), and IAT-19 (0.461). In-expected influence identified symptoms most strongly predicted by the earlier symptom system. The highest values were observed for IAT-9 (0.663), IAT-3 (0.652), IAT-11 (0.597), IAT-12 (0.595), IAT-10 (0.563), IAT-15 (0.555), IAT-13 (0.519), IAT-16 (0.516), IAT-8 (0.487), and IAT-6 (0.477).

As shown in Fig. 4 and Supplementary Table S3, bridge expected influence showed that daytime dysfunction was the dominant cross-domain bridge symptom (PSQI-7 = 0.703), followed by use of sleep medication (PSQI-6 = 0.658), sleep disturbance (PSQI-5 = 0.226), losing sleep due to late-night Internet use (IAT-14 = 0.101), concealment of Internet use (IAT-9 = 0.069), subjective sleep quality (PSQI-1 = 0.069), preferring the Internet to going out with friends (IAT-19 = 0.058), daily life affected by Internet use (IAT-8 = 0.035), thinking about online activities offline (IAT-15 = 0.032), and saying just a few more minutes online (IAT-16 = 0.031).

Stability, Accuracy, and Supplementary Analyses

Centrality stability was acceptable to strong, as shown in Fig. 5. The correlation-stability coefficient was 0.750 for in-expected influence and 0.439 for both out-expected influence and bridge expected influence. Edge-weight accuracy is shown in Fig. 6, and bootstrap difference tests for centrality indices are shown in Fig. 7. In the Supplementary Materials, the full weighted adjacency matrix is reported in Supplementary Table S1, the bootstrap difference test for node bridge expected influence is shown in Supplementary Figure S1, the sensitivity analysis is summarized in Supplementary Table S2, and the node bridge expected influence ranking is reported in Supplementary Table S3. Sensitivity analyses using an alternative regularization criterion produced a substantially similar edge-weight pattern ($r = 0.708$) and a moderately consistent bridge expected influence ranking ($\rho = 0.625$), supporting the robustness of the main directional conclusions.

Discussion

Principal findings and theoretical interpretation

This study used a cross-lagged panel network model to examine temporal symptom-level associations between Internet addiction and sleep problems among adolescents. The most important finding was a clear directional asymmetry: sleep-problem components showed stronger prospective associations with later Internet addiction symptoms than Internet addiction symptoms did with later sleep problems. In particular, daytime dysfunction emerged as the most influential cross-domain symptom, suggesting that impaired daytime functioning may represent an important upstream predictor of subsequent changes in Internet addiction symptoms. This pattern is consistent with recent evidence indicating that sleep disturbance may precede escalation in problematic digital-media behaviors by weakening self-regulation and increasing affective vulnerability (Liu et al., 2025).

The prominence of daytime dysfunction was reflected not only in its bridge role but also in its broad prospective associations with later Internet addiction symptoms. It predicted subsequent tendencies to use the Internet to block disturbing thoughts, lose sleep because of late-night Internet use, become irritable when Internet use was interrupted, and prefer online social or recreational activities. This pattern suggests that daytime dysfunction may be more than a downstream consequence of poor sleep. When sleep-related difficulties begin to impair adolescents' concentration, energy, emotional state, and everyday functioning, they may create a broader vulnerability that precedes changes in Internet-use behavior. This interpretation is consistent with evidence showing that daytime impairment is closely related to emotional, cognitive, and behavioral difficulties during adolescence (Sancho-Domingo et al., 2024).

These findings provide symptom-level longitudinal support for compensatory Internet use theory. Of particular relevance, daytime dysfunction predicted later Internet use aimed at blocking disturbing thoughts, suggesting that adolescents experiencing fatigue, poor concentration, or negative affect may

increasingly turn to online activities as an easily accessible means of distraction or emotional relief. The present findings therefore extend the compensatory perspective by suggesting that the functional consequences of poor sleep, rather than sleep disturbance in general, may be especially relevant to subsequent problematic Internet use. The findings are also consistent with the I-PACE model. Daytime fatigue and impaired functioning may increase affective vulnerability while simultaneously reducing the cognitive resources needed to regulate rewarding online behavior. In this context, Internet-based rewards may become more salient and disengagement more difficult. Rather than simply confirming the mechanisms proposed by I-PACE, the present network findings help identify a potentially important functional state within this process: daytime dysfunction may mark the point at which sleep-related vulnerability begins to exert broader prospective influence on problematic Internet-use symptoms. A recent symptom-network study similarly identified daytime dysfunction and sleep disturbance as important bridges between problematic smartphone use and poor sleep quality among adolescents with depression (Zhou et al., 2025).

The relatively weak Internet-to-sleep pathways further clarify the temporal organization of the relationship. These findings should not be interpreted as evidence that problematic Internet use is unimportant for sleep. Instead, they suggest that after prior sleep problems and the broader symptom system are taken into account, individual Internet addiction symptoms contribute comparatively little unique prospective influence on later sleep components. Prospective research nevertheless indicates that problematic screen use can predict subsequent sleep disturbance and broader mental-health difficulties (Nagata et al., 2026), while regulatory vulnerabilities associated with problematic screen use are also consistent with I-PACE assumptions regarding affective and executive-control processes (Grund & Luciana, 2025).

Taken together, the present findings are more consistent with a reciprocal but asymmetric pattern than with a fully symmetrical feedback process. Internet-related behavior may contribute to sleep disruption, but sleep-related daytime impairment appears to occupy a more upstream position in the longitudinal symptom network. One possible explanation is that the effects of problematic Internet use on sleep are mediated by more proximal nighttime behaviors that were not directly assessed in the present study, such as bedtime device use, notification exposure, delayed sleep timing, or cognitively and emotionally arousing online content (Pagano et al., 2023). Thus, the weaker Internet-to-sleep pathways may reflect limited unique symptom-level prospective effects rather than an absence of association.

Other symptom-level and demographic findings

Beyond daytime dysfunction, sleep medication use and sleep disturbance also showed notable bridge influence. These indicators may reflect relatively persistent or severe sleep dysregulation, and their prospective links with later Internet addiction symptoms are consistent with previous evidence connecting chronic sleep difficulties with compulsive digital behavior and poorer psychological adjustment (Oh & Heo, 2026). However, these findings should be interpreted more cautiously than those for daytime dysfunction, particularly because sleep medication use may also reflect underlying health conditions, treatment-seeking behavior, or greater sleep-problem severity. Within the Internet addiction

domain, the symptom reflecting neglect of responsibilities because of Internet use showed the strongest outgoing influence. This finding is noteworthy because it captures functional impairment rather than simply intensive engagement. Its position in the temporal network is consistent with recent conceptual work emphasizing that functional impairment is central to distinguishing problematic Internet use from high but nonpathological Internet engagement (Brand et al., 2025b).

This result also converges conceptually with the prominence of daytime dysfunction in the sleep domain. In both domains, symptoms reflecting disruption of real-world functioning appeared to be especially influential. This suggests that functional impairment may be more informative for understanding the development of problematic Internet use than exposure or symptom frequency alone. Once sleep problems or Internet use begin to interfere with concentration, responsibilities, academic functioning, or daily routines, the likelihood of broader symptom expansion may increase.

The receiving side of the network was characterized by concealment of Internet use, preference for online excitement, preoccupation, and mood-regulation motives. These symptoms may represent downstream manifestations of increasingly consolidated problematic Internet behavior. Similar patterns have been reported in longitudinal and network studies in which emotional coping motives and secretive Internet use were associated with more persistent problematic-use trajectories (Chen et al., 2025). These findings support the value of distinguishing symptoms that exert broader prospective influence from those that may primarily reflect the later consolidation of problematic Internet use.

The demographic findings provide additional context. Girls reported higher sleep-problem levels than boys at both waves, which is consistent with recent adolescent research linking female sex with greater subjective sleep disturbance and internalizing vulnerability (Wang et al., 2025). Older students and those in higher grades showed higher Internet addiction levels, which may reflect increasing academic demands, greater autonomy over device use, and the growing integration of online communication into peer relationships during later adolescence (Ren et al., 2026). Although these demographic differences do not explain the symptom-level temporal pathways directly, they may help identify subgroups in which sleep difficulties and problematic Internet use warrant closer attention.

Practical implications and limitations

The most direct practical implication of the present study is that prevention of adolescent Internet addiction may need to move beyond an exclusive focus on screen time. The findings suggest that daytime dysfunction may serve as an early functional marker of vulnerability to subsequent problematic Internet-use symptoms. Persistent fatigue, concentration difficulties, reduced academic functioning, and daytime emotional impairment may therefore provide useful warning signs before problematic Internet use becomes more established (Zheng et al., 2025).

This finding also supports integrating sleep-focused strategies into digital well-being interventions. Improving sleep regularity and reducing daytime impairment may lessen adolescents' need to use the Internet as a compensatory strategy, while strengthening self-regulation and alternative emotion-

regulation skills may reduce the likelihood that compensatory use develops into poorly controlled use. For adolescents who already show functional impairment related to Internet use, such as neglecting responsibilities, intervention may be more effective when it focuses on restoring daily functioning and self-regulatory capacity rather than simply reducing total time online.

From a methodological perspective, the study demonstrates the value of cross-lagged panel networks for identifying symptom-level temporal asymmetries that may be obscured by total-score analyses. In particular, this approach made it possible to identify daytime dysfunction as a potentially influential cross-domain predictor rather than treating sleep disturbance and Internet addiction as undifferentiated constructs. The use of bootstrap stability analyses, difference tests, and sensitivity analyses further strengthens confidence in the interpretation of the network findings and is consistent with recent methodological recommendations for psychological network research (Burger et al., 2023).

Several limitations should nevertheless be acknowledged. First, the two-wave design permits temporal prediction but does not establish causality. Daytime dysfunction should therefore be interpreted as an upstream prospective predictor within the network rather than a confirmed causal mechanism. Second, both sleep and Internet addiction were measured by self-report. Future studies incorporating objective sleep measures, device-use logs, and ecological momentary assessment could provide a more precise account of the timing and context of sleep–Internet interactions (Niu et al., 2026). Third, compensatory motives, negative affect, Internet-use expectancies, and executive control were not directly assessed. The interpretations based on compensatory Internet use theory and the I-PACE model should therefore be regarded as theoretically informed explanations that require direct testing in future longitudinal research.

Overall, the present study identified a reciprocal but clearly asymmetric longitudinal symptom network between sleep problems and Internet addiction in adolescents. The central finding was that daytime dysfunction showed the most prominent cross-domain role and may represent an important upstream predictor of subsequent changes in Internet addiction symptoms. This finding extends compensatory Internet use theory and the I-PACE framework by suggesting that the functional consequences of poor sleep may be particularly important in shaping later problematic Internet behavior. From a prevention perspective, improving daytime functioning, strengthening self-regulation, and reducing reliance on Internet use as a compensatory coping strategy may provide more targeted approaches than focusing on Internet exposure alone. This interpretation is consistent with emerging work emphasizing the need to integrate sleep, emotional regulation, and broader developmental demands in efforts to promote adolescent digital well-being (Zhu & Xue, 2025).

Conclusion

In a two-wave adolescent sample, sleep problems showed stronger prospective connections to later Internet addiction symptoms than Internet addiction symptoms showed to later sleep problems. Daytime dysfunction, sleep medication use, and sleep disturbance were key bridge symptoms, while

responsibility-related Internet addiction symptoms were prominent temporal drivers. These findings indicate that sleep-focused prevention and symptom-specific screening may improve early intervention for adolescent Internet addiction.

Declarations

Ethics declarations

Ethics approval and consent to participate

This study was approved by the Ethics Review Committee of Northwest Normal University (Approval No. 2025093). All procedures were conducted in accordance with the Declaration of Helsinki and relevant ethical guidelines and regulations in China. Prior to participation, informed consent was obtained from the participants' parents or legal guardians, and assent was obtained from all adolescent participants. Participation was entirely voluntary, and participants were informed that they could withdraw from the study at any time without any adverse consequences.

Clinical trial number

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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Author Contribution

Lili Liu: Conceptualization, Methodology, Formal analysis, Investigation, Data curation, Visualization, Writing – original draft, Writing – review & editing. Shuang Li: Conceptualization, Methodology, Formal analysis, Investigation, Data curation, Visualization, Writing – original draft, Writing – review & editing..

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Availability of data and materials

The datasets used in the current study are available from the corresponding author upon reasonable request.

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Figures

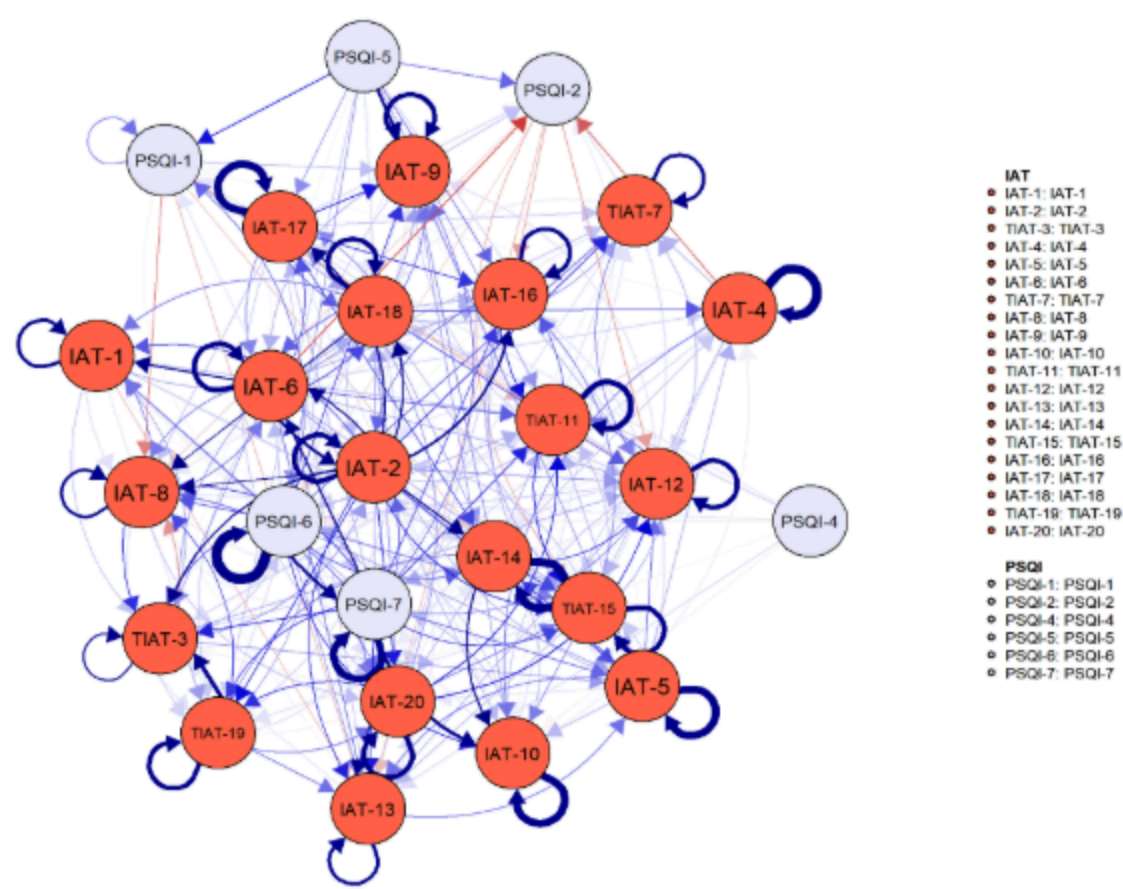


Figure 1

Cross-lagged network including autoregressive paths

Note. IAT = Internet Addiction Test; PSQI = Pittsburgh Sleep Quality Index

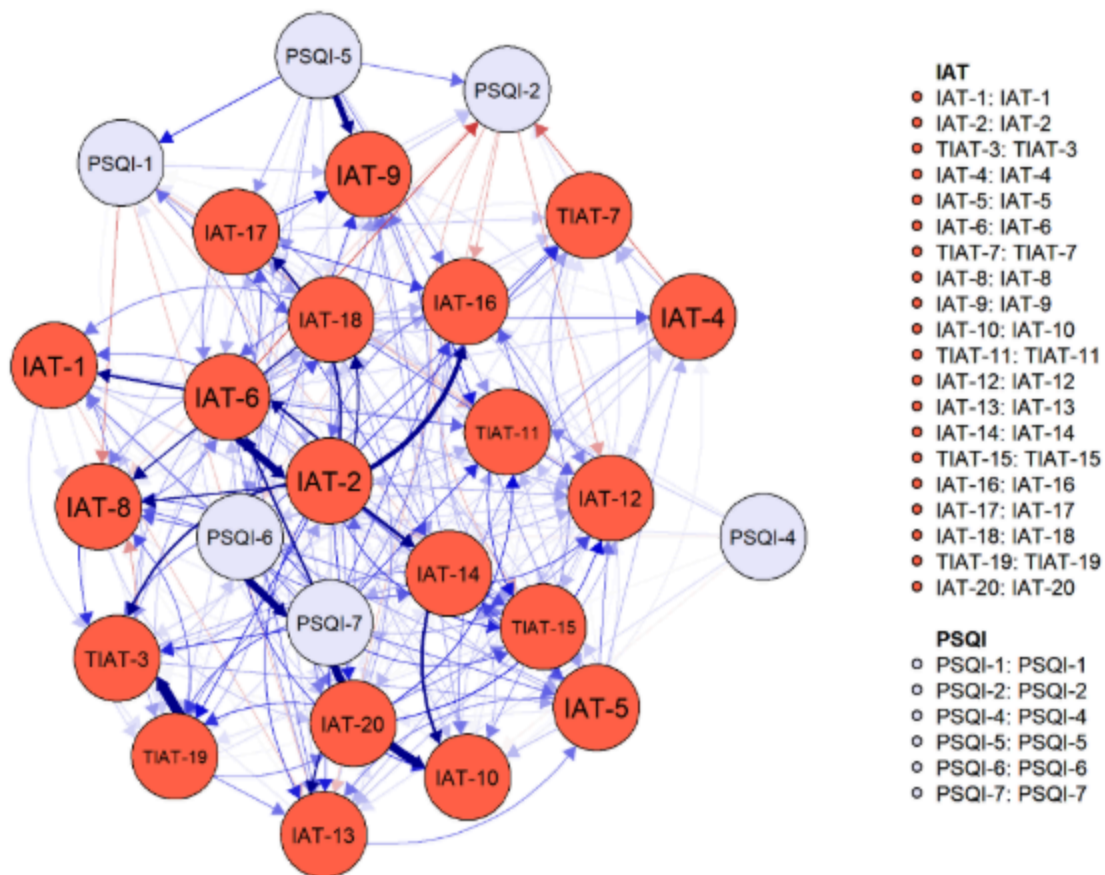


Figure 2

Non-autoregressive cross-lagged symptom network

Note. IAT = Internet Addiction Test; PSQI = Pittsburgh Sleep Quality Index

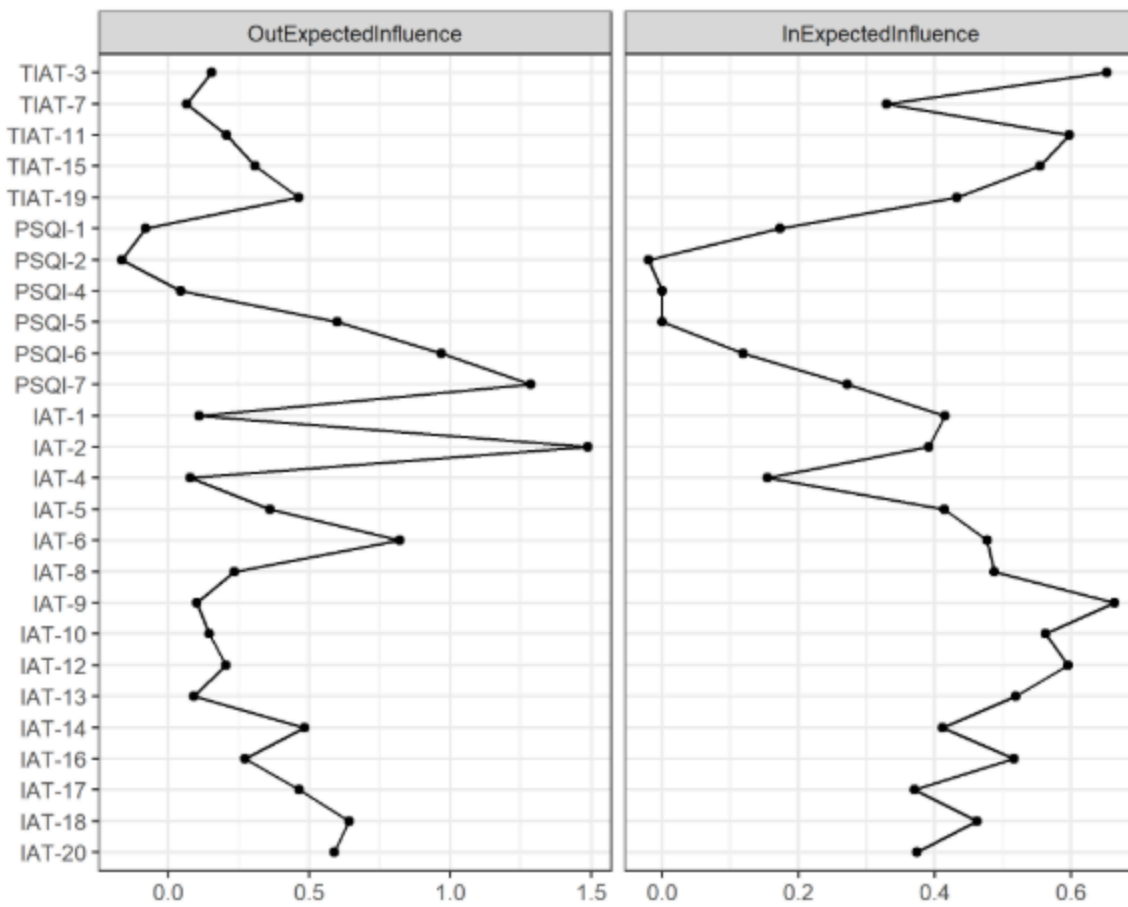


Figure 3

In-expected and out-expected influence

Note. IAT = Internet Addiction Test; PSQI = Pittsburgh Sleep Quality Index

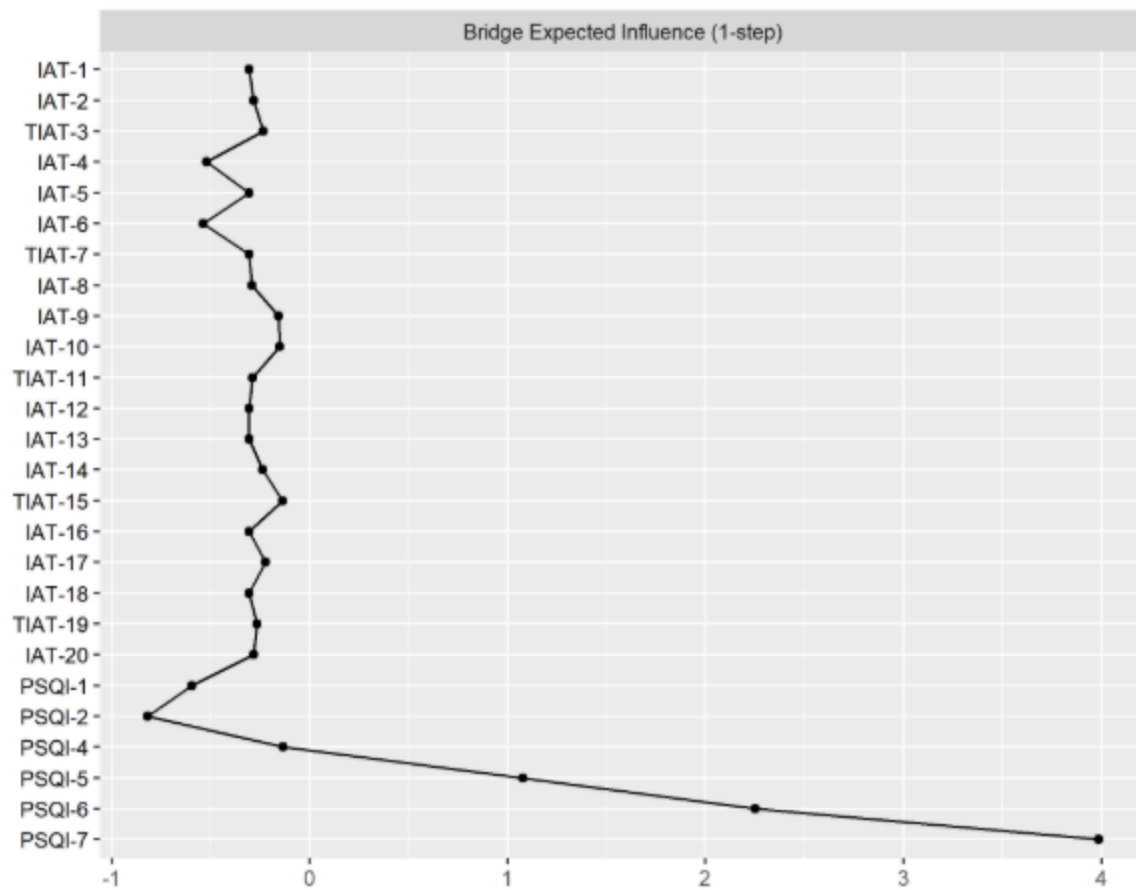


Figure 4

Bridge expected influence

Note. IAT = Internet Addiction Test; PSQI = Pittsburgh Sleep Quality Index

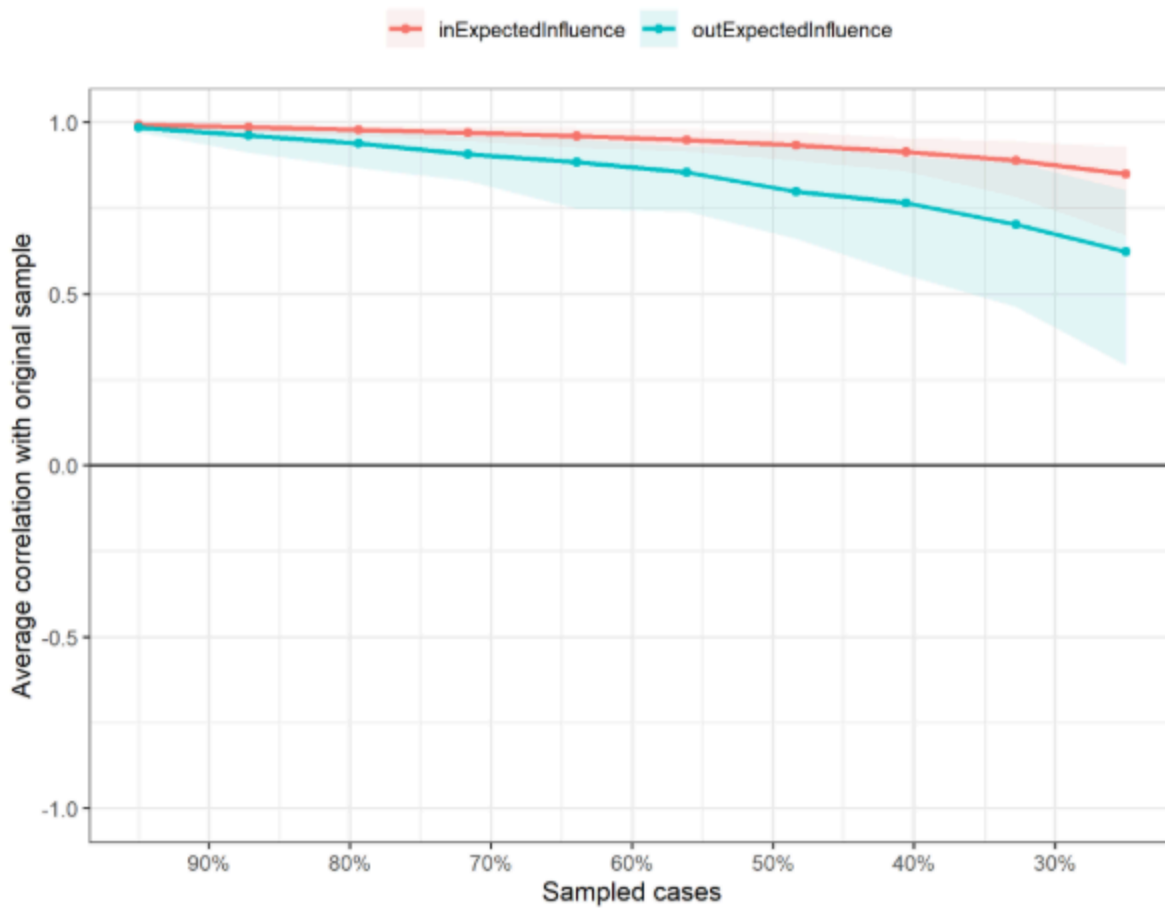


Figure 5

Centrality stability

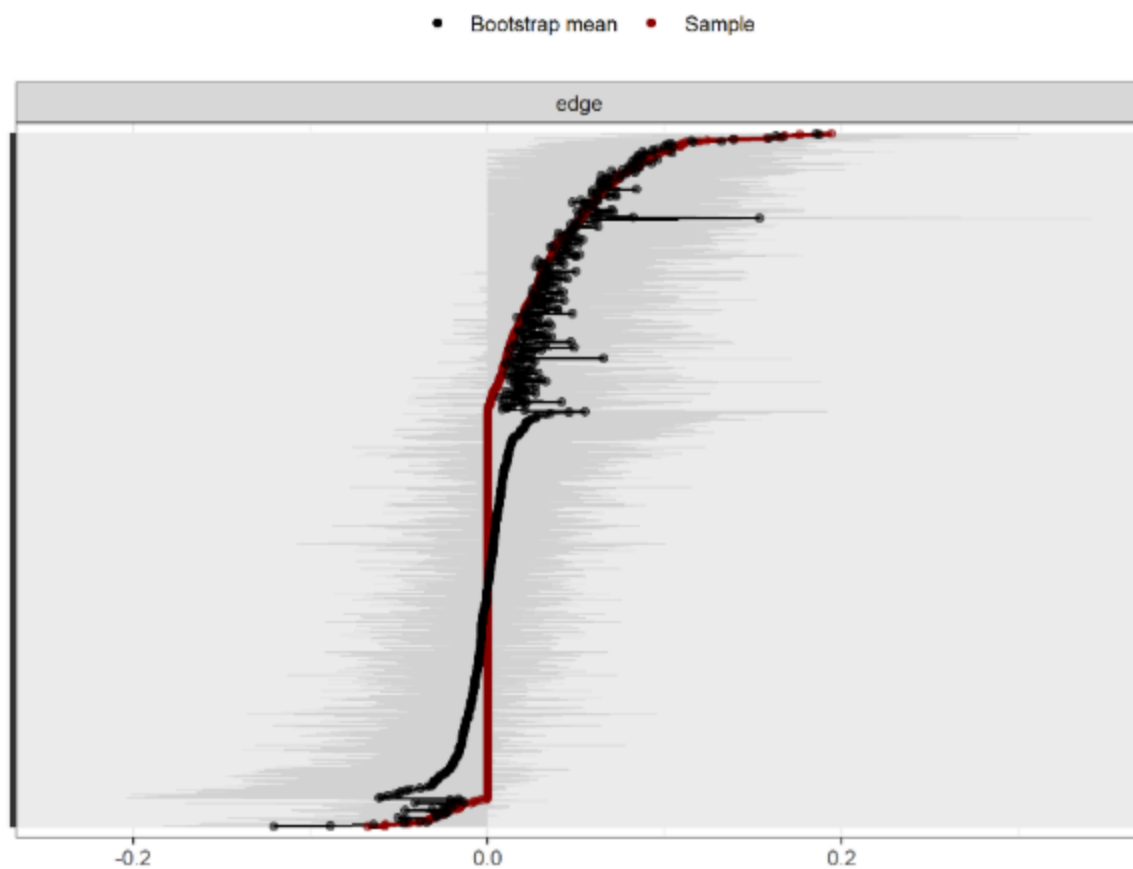


Figure 6

Bootstrap confidence intervals for edge weights

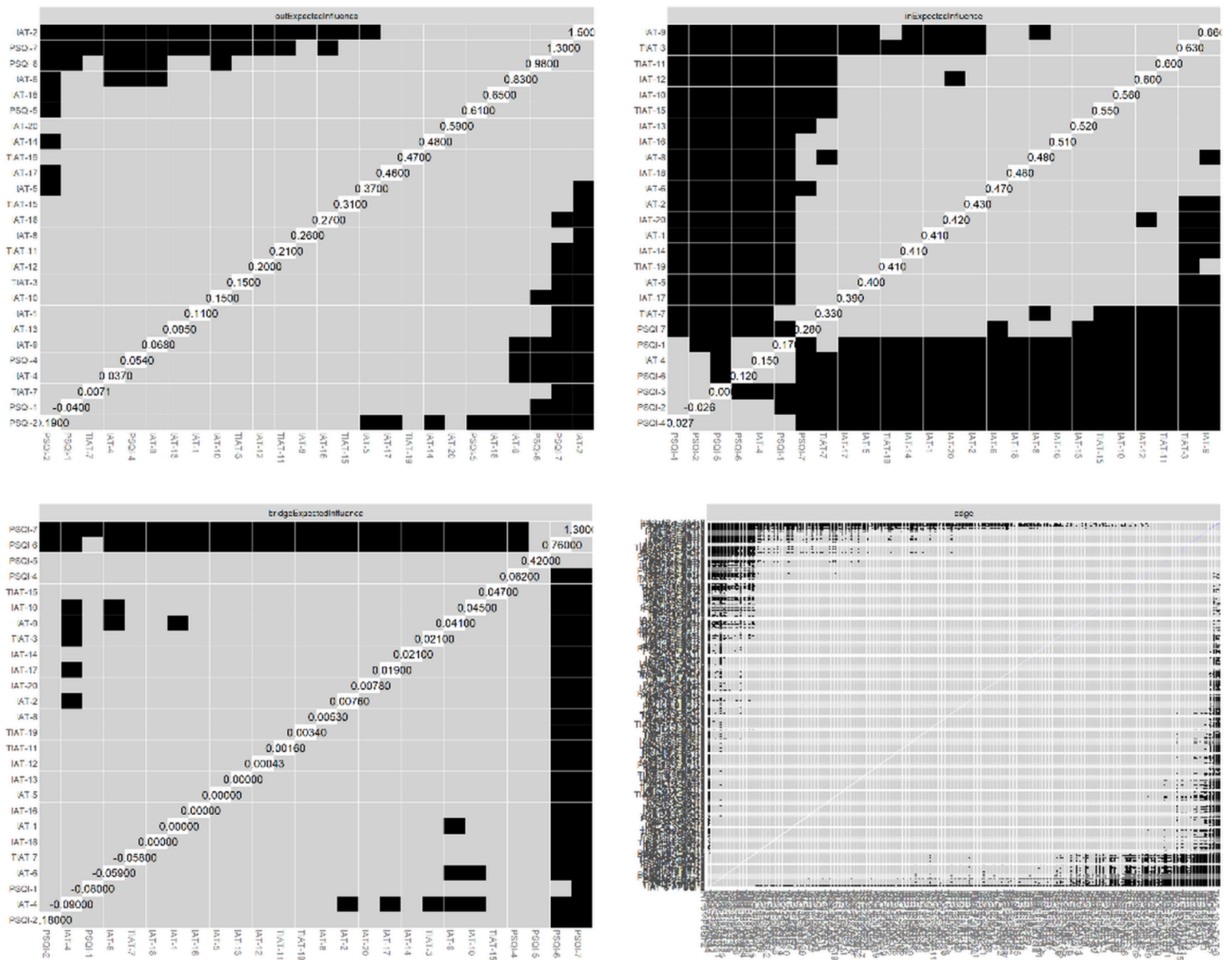


Figure 7

Bootstrap difference tests for centrality indices

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