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Understanding the relationships among adolescents' internet dependence, reward, cognitive control processing, and learning burnout: a network perspective in China

Haotian Wu[1†], Guangteng Meng[2,3†], Lingxiao Wang[4,5], Jing Xiao[1*], Kesong Hu[6*] and Qi Li[1*]

Abstract

Alterations in the reward and cognitive control systems are commonly observed among adolescents with internet dependence (ID), and this impairment is often accompanied by social dysfunctions, such as academic burnout. However, the intercorrelations among ID, reward, cognitive control processing, and learning burnout remain unclear. We recruited 1074 Chinese adolescents to investigate the complex interrelationships among these variables using network analysis. The resulting network revealed patterns that connected ID to the behavioral inhibition/activation system (BIS/BAS), self-control, and learning burnout; these results exhibited reasonable stability and test–retest consistency. Throughout the network, the node of BAS-drive was the critical influencing factor, and the node of self-control was the protection factor. In addition, several symptoms of learning burnout and ID were positively associated with sensitivity to punishment. As revealed by the network comparison test, the network constructed among internet dependent (ID) group differed from the network constructed among internet nondependent (IND) group not only in the edges between BIS and learning burnout but also in terms of the edges associated with learning burnout. In conclusion, this study provides insights into the complex mechanisms underlying ID among adolescents from the perspective of the network relationships between core influencing factors and negative consequences. It validates the dual-system model of risky behavior among adolescents and offers a foundation for early warning and interventions for ID in this context.

Keywords Internet dependence, BAS/BIS, Self-control, Learning burnout, Adolescents, Network analysis

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Introduction

Adolescents are susceptible to internet dependence (ID) [1]. In China, the adolescent internet usage rate has reached 13.5%, which is significantly higher than that of the adult population, as reported in the 47th Statistical Report on internet development [2]. The COVID-19 pandemic has likely exacerbated this trend due to the associated quarantine and increased stress levels. Recent studies have shown that 37.7% of Chinese adolescents developed ID during the COVID-19 pandemic [3, 4]. ID among adolescents is associated with a series of social dysfunctions, including emotional exhaustion [5], low motivation to study [6], poor teacher–student relationships [7], low learning self-efficacy [8], and physical fatigue [5]. In light of its prevalence and negative consequences, it is necessary to prevent individuals, especially susceptible adolescents, from becoming addicted to the internet.

There are no consistent criteria for the definition and diagnosis of ID [9]. Young [10] conceptualized ID as a generalized impulse control disorder, while Ko et al. [11] studied ID based on the diagnostic framework of substance use disorders. Moreover, different assessment tools and diagnostic criteria are used in this context [12]. For example, Young's Diagnostic Questionnaire (YDQ) [13] focuses on eight core symptoms. In contrast, the Internet Addiction Test (IAT) [13] and Chen's Internet Addiction Scale (CIAS) [14] include peripheral symptoms other than impaired control, such as time management and social problems. Despite this heterogeneity, it is widely accepted that ID is characterized by a deficiency in the reward and inhibition mechanism [15–17] and that it may be accompanied by impairments in psychological and social functioning [18, 19], which eventually lead to psychological, social, educational, and occupational problems [10].

The dual-system model of adolescent risk-taking proposes that the imbalance between weakened cognitive control systems and enhanced reward-seeking in adolescence (as compared with children and adults) is an important factor contributing to high-risk behaviors such as ID as well as academic burnout [20–22]. This viewpoint has been supported by a significant amount of behavioral and neurobiological research. First, individuals with ID exhibit impaired self-control [23]. University students with ID exhibit larger conflict effects than healthy controls [15, 24, 25] as well as smaller amplitudes of nogo-N2 and larger amplitudes of nogo-P3, which are associated with conflict monitoring and response evaluation [26, 27]. Brain imaging studies have shown more activation in executor-control-related brain regions such as the dorsolateral prefrontal cortex (DLPFC) and inferior frontal gyrus (IFG) in individuals with ID than in healthy controls [28–30]. Additionally, individuals with ID exhibit reward processing deficits [31]. Research has found that reward-seeking is an indicator for the prediction and evaluation of ID. Individuals with high reward-seeking personality traits are more prone to ID [32, 33]. Individuals with ID have high reward motives but lack inhibition with regard to potential risks, and they are more inclined toward immediate rewards than toward long-term benefits [34]. When presented with online gaming cues, individuals with ID experience stronger cravings to play games, and brain regions associated with craving and reward processing, such as the striatum and orbitofrontal cortex, are activated in this context [33–35].

Addressing the adverse impact of adolescent ID on social functioning in the context of academic performance is one of the core aims of this research. The adverse impact of adolescent ID on social functioning primarily manifests in academic performance [36, 37]. It is widely believed that a typical manifestation of ID is learning burnout, which includes four aspects: mental and physical exhaustion, the lack of learning self-efficacy, and alienated relationships with teachers [38, 39]. Students with ID feel nervous and frustrated during learning, and psychologically, they feel unable to concentrate on their studies, resulting in a negative emotional experience toward learning [40, 41]. ID also has adverse effects on physical health. Symptoms such as headaches, eye fatigue, hearing issues, and sleep disorders are often significantly linked with ID [42]. Due to the increasing prevalence of internet dependence, learning motivation, such as intrinsic goal orientation and self-efficacy in learning, can be weakened [8, 37]. Such individuals, who exhibit a constant addiction to the world of the internet, find it difficult to cope with interpersonal relationships in the real world, thus leading to poor communication with teachers and difficulty receiving support from them [43–46].

Learning burnout is linked to both reward-seeking and self-control. Using structural equation modeling, van Beek [47] found that high scores on the behavioral activation system (BAS) scale are positively associated with study engagement, which in turn is negatively related to exhaustion and the intention to quit. Furthermore, academic burnout is negatively associated with self-control [48–50]. Insufficient self-control may cause students to have inaccurate perceptions of their own abilities, which further exacerbate their academic burnout and even cause them to develop study-weariness [49]. In contrast, the cultivation of self-control can effectively enhance students' abilities to manage their goals [51], thereby improving their resistance to academic burnout.

Although numerous studies have confirmed that reward-seeking and cognitive control, which constitute the two core features of ID, as well as social functioning, are impaired, the complex relationships among ID, reward-seeking, cognitive control, and learning burnout

are not clear. Network analysis methods provide a solution to this problem by including all potentially interconnected factors or symptoms in a network [52, 53]. This analysis can facilitate the swift establishment of a model of the relationships among multiple variables and thus offer the possibility of exploring complex psychological systems [54]. To date, network analysis has been employed to investigate the internal symptoms of ID [55, 56] and the interactions between ID and individual psychological symptoms in the network [57–59]. Although some studies have examined the interactions between problematic mobile phone use (PMPU) and reward-seeking, self-control, and teacher–student relationships from a network perspective [60, 61], to date, no research has explored the network-based relationship between the two core features of adolescents' ID, i.e., reward-seeking and failure of self-control, and the typical negative consequences of learning burnout in this context.

To address these issues, this study uses network analysis to explore the core characteristics of and complex patterns underlying the relationships among ID symptoms, reward and punishment sensitivity, self-control, academic burnout, and their subdimensions in the context of adolescents. Simultaneously, the networks of internet dependent (ID) group and internet non-dependent (IND) group are compared to explore the similarities and differences between these two networks. Based on the extant literature, this study proposes three hypotheses. First, reward-seeking is a motivational system of ID that is closely related to both ID and learning burnout [15, 31, 33, 47]. Therefore, we expect the behavioral activation system (BAS) to constitute a core node in the entire network of ID. Second, considering the protective effects of self-control on ID and learning burnout that have been reported in previous research [23, 50], we predict that self-control is an inhibitory factor in the network of ID, playing a defensive role against ID. Third, since reward and self-control systems are core elements of adolescent with ID [32, 62] and since learning burnout is a typical negative outcome of ID, we expect that the reward, self-control, and learning burnout variables form a complex network pertaining to ID group that differs significantly in structure and global strength from that of IND group.

Method

Participants and procedure

We recruited 1133 Chinese adolescents from four public secondary schools, with ages ranging from 12 to 18 years and an average age of 15.13 years (SD = 1.24). The recruitment posters were displayed on bulletin boards by the school grade directors, promising stationery as a reward after the test. After obtaining written consent from both guardians and participants, participants engaged in the experiment in designated school computer rooms post-school hours. Before the experiment, teachers emphasized maintaining silence, and wooden cubicles were installed to minimize social desirability bias arising from student interaction. Students filled out personal information, such as gender, educated time, online time per day, etc. (see Table S1), and completed the questionnaires independently through an online platform (https://wj.qq.com/). Participants who were inattentive (i.e., a question "choose 3 for this question") or selected the same response across all questionnaires were excluded. 45 respondents who failed an attention check and 14 respondents who selected the same response across all questionnaires were excluded before data analysis, which yielded an effective response rate of 94.8%. A total of 1074 adolescent data were included in subsequent analyses, comprising 553 boys (51.49%) and 521 girls (48.51%). After the experiment, each participant received stationery and a monetary compensation of 10 RMB (approximately $1.5). Both participants and their guardians provided written informed consent in accordance with the principles of the Declaration of Helsinki. Further detailed demographic information can be found in Table S1.

Measures

Young's diagnostic questionnaire for internet addiction (YDQ)

YDQ is modified in line with the DSM-IV criteria for pathological gambling and is used to assess ID [13]. YDQ includes eight questions, which indicate a score of 1 point for "yes" and a score of 0 points for "no"; the total score ranges from 0 to 8 points. Higher scores reflect a higher level of ID. According to the diagnostic criteria established by Young [13], Participants who answered "yes" to five or more of the criteria were classified as the internet dependent (ID) group, and the remainder were classified as the internet nondependent (IND) group. Additionally, we have established a high group (scores 6–8), a middle group (scores 3–5), and a low group (scores 0–2) based on the YDQ scores to investigate the differences in internet characteristics across varying levels of internet dependence severity. The Chinese version of the YDQ has been reported to exhibit good psychometric properties [63] and is used in this study. In the present study, the Cronbach's alpha coefficient for ID was 0.80.

Behavioral inhibition/approach system (BIS/BAS) scales

The BIS/BAS scales are used to assess the behavioral inhibition system (BIS) and the behavioral activation system (BAS) [64]. The validated Chinese version of the BIS/BAS scales used in the current study includes 18 items in addition to 4 filler items; specifically, it includes the Behavioral Inhibition System Scale (5 items) and the Behavioral Approach System Scale (13 items) [65]. The latter scale

can be divided into three subscales: drive (node: BAS1), reward responsiveness (node: BAS2), and fun-seeking (node: BAS3). All items were scored on a 4-point Likert scale ranging from 1 (totally disagree) to 4 (totally agree). The Cronbach's alpha coefficients for the BIS and BAS in the current sample were 0.77 and 0.85, respectively.

Self-control scale (SCS)

The Self-Control Scale (SCS) is a 36-item questionnaire that has been widely used to measure participants' dispositions toward self-control [66]. The items included in the SCS are scored on a five-point Likert scale ranging from 1 ("definitely disagree") to 5 ("definitely agree"). Although the original scale consists of five subscales, i.e., general capacity for self-discipline, deliberate/nonimpulsive action, healthy habits, work ethics, and reliability, previous studies have treated the total score of the scale as a node in the network to ensure high reliability [67]. Therefore, we included the total SCS score as an indicator of self-control (node: SCS). Higher scores indicate stronger control ability. The Cronbach's alpha coefficient for this scale in the current study was 0.89.

Learning burnout scale (LBS)

The Chinese version of the LBS, which assesses learning burnout [38], was used for the current study. This scale contains 21 items, and each item is scored on a five-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree). The LBS includes four subscales: mental exhaustion (node: LBS1), lack of learning self-efficacy (node: LBS2), alienated relationship with teachers (node: LBS3), and physical exhaustion (node: LBS4). The Chinese version of the LBS has been validated and shown to exhibit robust construct validity and test–retest reliability [38]. In the present study, the Cronbach's alpha coefficient for the LBS was 0.88.

Statistical analysis

The means, standard deviations, Cronbach's alpha coefficients, and zero-order Pearson correlations of all scales and subscales were calculated to understand the characteristics of the research variables and the relationships among them (Table 1). Independent sample *t* tests were performed to examine the differences between ID group and IND group in the BIS/BAS, LBS, and SCS scores. R software (version 4.2.0, available at https://cran.r-project.org/) was used for data entry, descriptive analyses, and network analysis.

Each participant represented a case within the network. The computed scores of each scale and subscale for all cases were then used as the "nodes" of the network, whereas the "edges" between these nodes were used to represent the putative associations (with partial correlations ranging from −1 to 1). In this way, a visual network was constructed to display the overall correlation structure [52, 53]. Our dataset did not contain any missing data because all question items were identified as "mandatory" on the online platform.

In this study, the centrality and the expected influence of each node were computed using the R packages igraph (version 1.3.2, https://cran.r-project.org/web/packages/igraph/index.html), qgraph (version 1.9.2, https://cran.r-project.org/web/packages/qgraph/index.html) and networktools (version 1.5.0, https://cran.r-project.org/web/packages/networktools/index.html). Conventionally shown in terms of standardized z scores, centrality refers to the interconnectedness of a given node in the network. First, all three centrality indices (i.e., strength, closeness, and betweenness) were calculated. Together,

Table 1 Means, standard deviations, Cronbach's alpha coefficients, and zero-order Pearson correlations among the variables ($n = 1074$)

Study variables	1	2	3	4	5	6	7	8	9	10
1. YDQ	1.00									
2. BIS	0.11***	1.00								
3. BAS1	0.10***	0.33***	1.00							
4. BAS2	0.04	0.53***	0.60***	1.00						
5. BAS3	0.20***	0.35***	0.53***	0.52***	1.00					
6. LBS1	0.42***	0.04	0.03	-0.03	0.25***	1.00				
7. LBS2	0.18***	-0.14***	-0.12***	-0.24	-0.02	0.10**	1.00			
8. LBS3	0.27***	0.08**	0.12***	0.03	0.23***	0.58***	0.10*	1.00		
9. LBS4	0.29***	0.23**	0.08**	0.11***	0.22***	0.49***	0.04	0.53***	1.00	
10. SCS	-0.35***	0.03	0.03	-0.02	-0.29***	-0.57***	-0.15***	-0.43***	-0.48***	1.00
Mean	3.35	14.75	11.62	16.24	11.27	18.69	14.69	9.43	10.62	114.61
SD	2.51	3.16	2.48	2.79	2.39	7.49	4.86	4.09	4.53	17.09
Range	0–8	5–20	4–16	5–20	4–16	8–40	5–25	4–20	4–20	56–176
α	0.80	0.77	0.73	0.71	0.68	0.91	0.88	0.84	0.87	0.89

Note: **YDQ**: Young's Diagnostic Questionnaire; **BIS**: Behavioral Inhibition System; **BAS1**: Drive; **BAS2**: Reward Responsiveness; **BAS3**: Fun-Seeking; **LBS1**: Emotional Exhaustion; **LBS2**: Lack of Learning Self-Efficacy; **LBS3**: Alienated Relationship with Teacher; **LBS4**: Physical Exhaustion; **SCS**: Self-Control Scale. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

these indices denoted the relative importance of a node within the whole network. Robinaugh et al. [68] argued that "expected influence (EI)" is a more appropriate measure than strength centrality when the estimated network contains both positive and negative edges. Therefore, in this study, EI was included as the fourth centrality index for each node in the network. EI involves two steps: step 1 focuses on the sum of all edges extending from a given node, while step 2 encompasses the sum of the expected influences of each node connected to the initial node plus the expected influence of the initial node from step 1.

The bootstrapping method was employed to examine the accuracy of our network (2000 iterations) using the R packages bootnet (version 1.5, https://cran.r-project.org/web/packages/bootnet/index.html) and ggplot2 (version 3.3.6, https://ggplot2.tidyverse.org/). First, nodes were bootstrapped to test the stability of strength centrality. Second, the edge-weight accuracy test and the bootstrapped difference test were conducted to investigate whether the edge weights and centrality indices would differ significantly from each other. Finally, the correlation stability coefficient (CS coefficient) was calculated to quantify the results of the subset bootstrap. A CS coefficient of above 0.5 is necessary for the centrality indices to be considered stable [69].

To examine the differences between ID and IND groups, as well as the differences among high, middle, and low YDQ groups in further detail, the network comparison tests were performed using the R package Network Comparison Test (version 2.2.1, https://cran.r-project.org/web/packages/NetworkComparisonTest/index.html). Global strength (i.e., the sum of the LBS connections exhibited by all pairs of nodes in the network), invariance of structure (i.e., the value of the maximum difference between matrices consisting of all edge strengths), and edge weights of the two networks were computed. In the two-tailed permutation tests (10,000 times), the significance threshold was set as $p<0.05$.

Results

Descriptive statistics

To understand the relationships between ID and other factors among adolescents, we first aimed to examine these relationships among our participants by conducting a network analysis. In our sample of 1074 cases, the mean total YDQ score was 3.35 (SD=2.51). Table 1 presents the descriptive statistics and zero-order Pearson correlations pertaining to the research variables. Network analysis was further performed on the original data.

Independent sample *t* tests (Table 2) revealed that compared to IND group, ID group exhibited significantly lower self-control ability ($p<0.001$) and higher levels of BIS ($p=0.005$), BAS ($p<0.001$), and learning burnout ($p<0.001$).

Network analysis

Figure 1A depicts a network model that integrates ID, behavioral inhibition/activation system, learning burnout, and self-control. A centrality analysis of the network showed that BAS1 exhibited the highest EI (Fig. 1B & Table S2), which was significantly higher than that of all the other nodes (Fig. S1). On the other hand, the nodes of the network were relatively predictable. The mean node predictability was 0.39 and ranged between 0.10 (LBS2) and 0.54 (BAS2), thus suggesting that the surrounding nodes could account for 39% of the variance in each node. Concerning the trustworthiness of the network, the centrality stability coefficient was high (Fig. S2).

The bootstrap tests of the edge weight accuracy indicated reasonable precision with regard to the ten nodes of the network (Fig. 2A). With the exceptions of the edges between nodes within the same orientation, six edges were significantly stronger than other edges, i.e., the

Table 2 Mean scores (SDs) of the scales and subscales as well as a comparison between the ID and IND groups

Scale	Total sample ($n=1074$)	ID group ($n=385$)	IND group ($n=689$)	t	95% CI	Cohen's d
YDQ	3.35 (2.51)	6.22 (1.04)	1.75 (1.43)	58.75	[4.32, 4.61]	3.72
BIS	14.75 (3.16)	15.11 (3.08)	14.55 (3.20)	2.82	[0.17, 0.96]	0.17
BAS	39.13 (6.41)	40.21 (6.10)	38.53 (6.50)	4.15	[0.89, 2.47]	0.25
BAS1	11.62 (2.48)	12.03 (2.46)	11.39 (2.46)	4.1	[0.33, 0.95]	0.25
BAS2	16.24 (2.79)	16.32 (2.82)	16.19 (2.78)	0.75	[–0.22, 0.48]	0.05
BAS3	11.27 (2.40)	11.85 (2.35)	10.95 (2.35)	6.06	[0.61, 1.20]	0.37
LBS	53.42 (14.72)	61.25 (13.00)	49.05 (13.78)	14.19	[10.51, 13.89]	0.87
LBS1	18.68 (7.48)	22.48 (7.31)	16.56 (6.71)	13.43	[5.06, 6.79]	0.82
LBS2	14.68 (4.86)	15.80 (4.49)	14.07 (4.96)	5.79	[1.14, 2.30]	0.12
LBS3	9.43 (4.09)	10.93 (3.99)	8.59 (3.90)	9.37	[1.85, 2.84]	0.57
LBS4	10.62 (4.53)	12.04 (4.25)	9.83 (4.49)	7.9	[1.66, 2.76]	0.48
SCS	114.61 (17.09)	108.65 (17.15)	117.93 (16.14)	–8.84	[–11.34, – 7.22]	–0.54

Note: **YDQ**: Young's Diagnostic Questionnaire; **BIS**: Behavioral Inhibition System; **BAS1**: Drive; **BAS2**: Reward Responsiveness; **BAS3**: Fun-Seeking; **LBS1**: Emotional Exhaustion; **LBS2**: Lack of Learning Self-Efficacy; **LBS3**: Alienated Relationship with Teacher; **LBS4**: Physical Exhaustion; **SCS**: Self-Control Scale

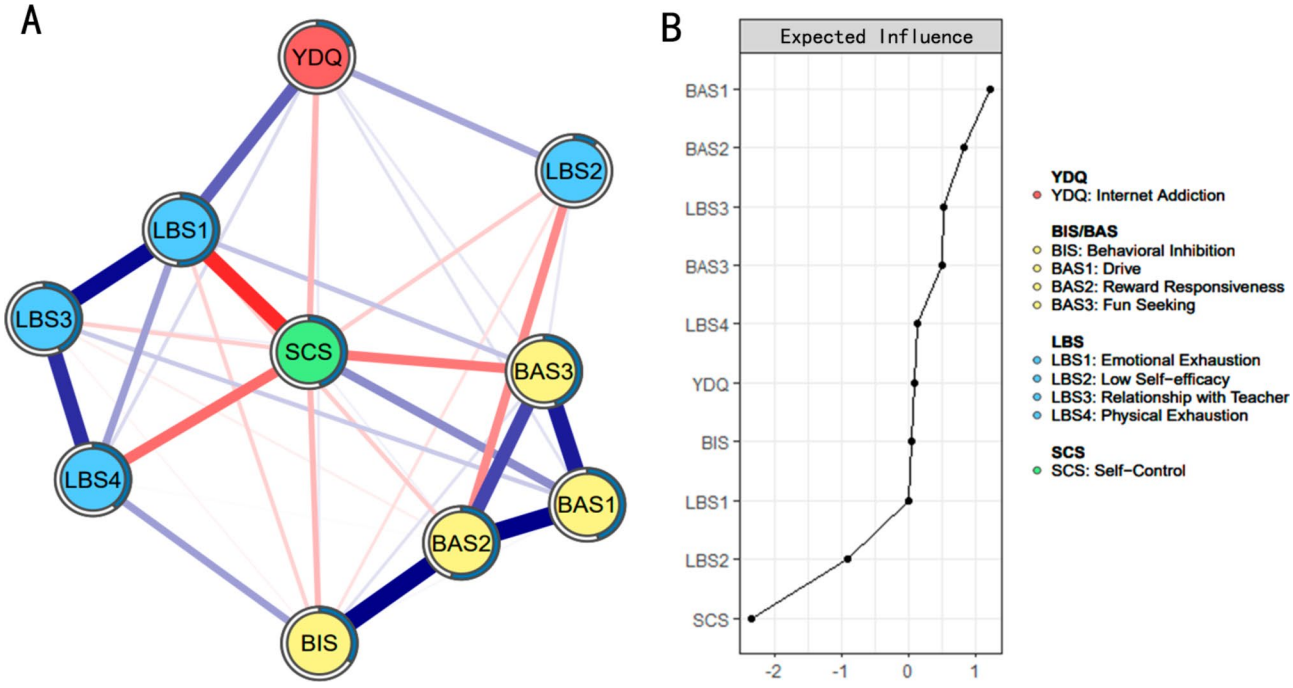

Fig. 1 (**A**) Graphical representation of the network model of ID, behavioral inhibition/activation system, self-control, and learning burnout. (**B**) Standardized EI centrality estimates. Note Blue edges indicate positive relations, and red edges indicate negative relations. Thicker edges represent stronger associations. **YDQ**: Young's Diagnostic Questionnaire; **BIS**: Behavioral Inhibition System; **BAS1**: Drive; **BAS2**: Reward Responsiveness; **BAS3**: Fun-Seeking; **SCS**: Self-Control Scale; **LBS1**: Emotional Exhaustion; **LBS2**: Lack of Learning Self-Efficacy; **LBS3**: Alienated Relationship with Teacher; **LBS4**: Physical Exhaustion (the thickest edge represents a value of 0.38)

edges between LBS1 and YDQ, between BAS1 and SCS, between BIS and LBS4, between SCS and LBS1, between SCS and LBS4, and between SCS and BAS3 (Fig. 2B).

We compared the networks of ID group and IND group (Fig. 3), in which context the average layout and the maximum were fixed using the *average layout* function. A significant difference was observed between the network structures pertaining to ID group and IND group ($M=0.204$, $p=0.015$), but no significant differences in global strength were observed ($S=0.680$, $p=0.916$). Next, we investigated which edges differed between ID group and IND group. Three edges differed between ID group and IND group: the connection between nodes BIS and LBS2, the connection between nodes LBS2 and LBS4, and the connection between nodes LBS3 and LBS4 ($ps \leq 0.048$). In ID group, the edge weight between nodes BIS and LBS2 was −0.30, contrasting with −0.09 in IND group. Similarly, the edge weight between nodes LBS2 and LBS4 in Dependents was −0.19, compared to 0.09 in Nondependents, and the edge weight between nodes LBS3 and LBS4 in Dependents was 0.37, versus 0.56 in IND group. Fig. S2 shows the standardized centrality estimates of the networks of ID group and IND group. In addition, the expected influence of the two network models was determined (Fig. 3C).

We compared the differences of the networks among high, middle, and low groups using the average layout function to fix the average layout and maximum (Fig. S3). For the high versus middle groups, no significant differences were found in network structures ($M=0.211$, $p=0.090$) or global strength ($S=0.491$, $p=0.501$), except for a notable difference in the LBS2-LBS4 connection ($p<0.001$). The edge weight of connection between nodes LBS2 and LBS4 in the high group was −0.29 and 0.02 in the middle group. In the comparison between the high group and low group, significant differences emerged in network structures ($M=0.222$, $p=0.035$), but not in global strength ($S=0.333$, $p=0.556$). The LBS2-LBS4 connection significantly varied between these groups ($p<0.001$). The edge weight of connection between nodes LBS2 and LBS4 in the high group was −0.29 and 0.11 in the low group. Lastly, comparing the middle and low groups, no significant differences were detected in network structures ($M=0.150$, $p=0.367$) or global strength ($S=0.158$, $p=0.753$), with no differing edges identified. In addition, the expected influence of the three network models was determined (Fig. S4).

Discussion

Based on a review of the literature, this study is the first to use network analysis to explore the interactions among ID in adolescents, the corresponding core risk factors (reward and cognitive control processing), and their negative consequences, such as learning burnout. The

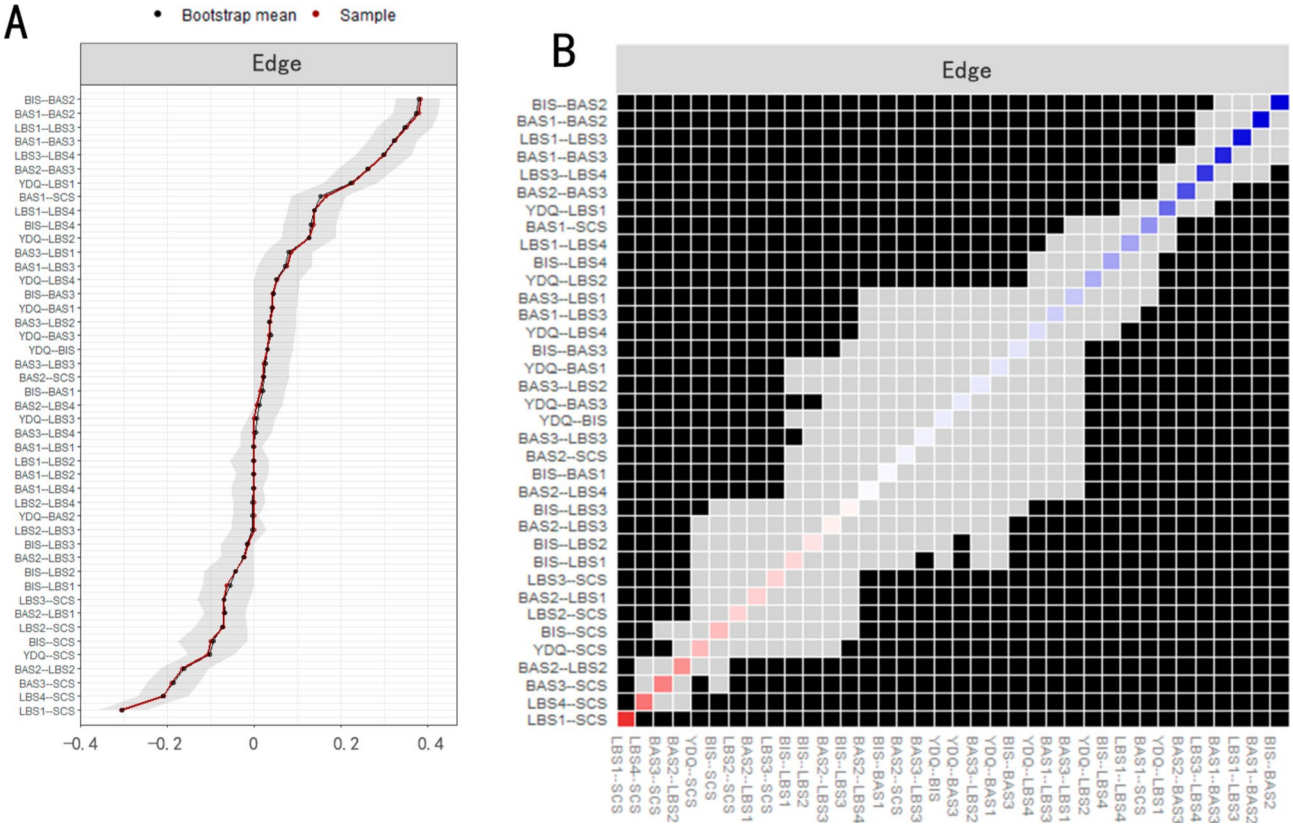

Fig. 2 (**A**) Bootstrapped 95% confidence intervals of the edge weights of the network; (**B**) Nonparametric bootstrapped difference tests for the edge weights of the network. Note The red line indicates the sample values, and the gray area represents 95% confidence intervals. All bootstrap confidence intervals were sufficiently small to ensure a fair amount of confidence regarding their stability. Black boxes represent nodes that do differ significantly from one another, while gray boxes indicate nodes that do not differ significantly from one another. The diagonal represents the standardized node's expected influence. **YDQ**: Young's Diagnostic Questionnaire; **BIS**: Behavioral Inhibition System; **BAS1**: Drive; **BAS2**: Reward Responsiveness; **BAS3**: Fun-Seeking; **SCS**: Self-Control Scale; **LBS1**: Emotional Exhaustion; **LBS2**: Lack of Learning Self-Efficacy; **LBS3**: Alienated Relationship with Teacher; **LBS4**: Physical Exhaustion

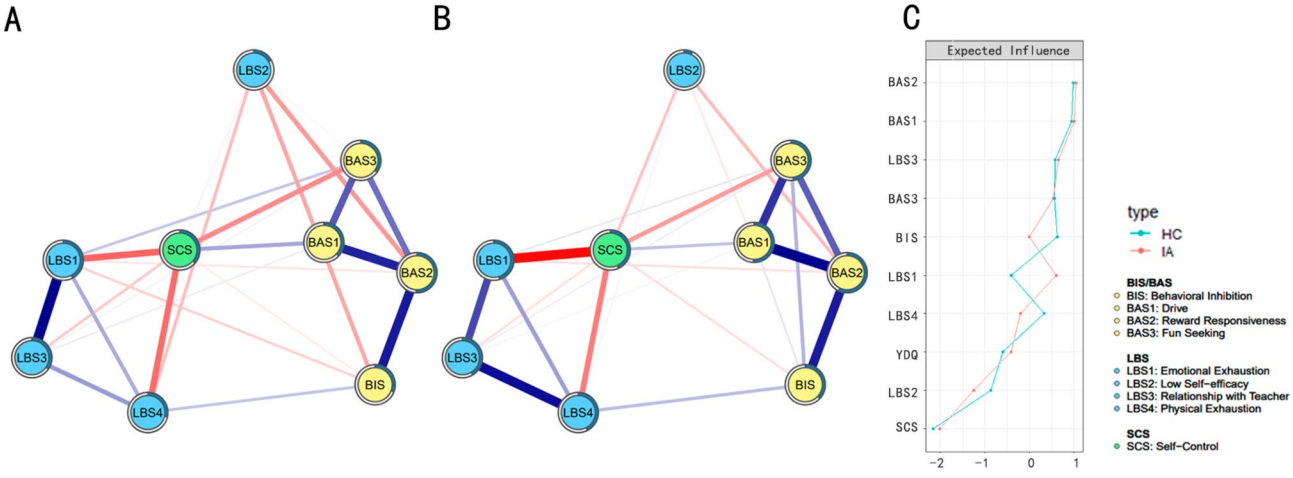

Fig. 3 (**A**) The network models of the ID group ($n = 385$) and (**B**) the IND group ($n = 689$); (**C**) standardized EI estimates of the networks of the ID and IND groups. NoteBlue edges indicate positive relations, and red edges indicate negative relations. Thicker edges represent stronger associations. **YDQ**: Young's Diagnostic Questionnaire; **BIS**: Behavioral Inhibition System; **BAS1**: Drive; **BAS2**: Reward Responsiveness; **BAS3**: Fun-Seeking; **LBS1**: Emotional Exhaustion; **LBS2**: Lack of Learning Self-Efficacy; **LBS3**: Alienated Relationship with Teacher; **LBS4**: Physical Exhaustion; **SCS**: Self-Control Scale

network model revealed that ID and other factors were interconnected in the form of a network. BAS drive was the core node, and self-control was connected with other nodes more strongly, with the former acting as a susceptibility factor pertaining to ID and the latter acting as a protective factor. In addition, ID group was different from healthy controls in terms of network structures. This finding was particularly evident in the edges connecting behavioral inhibition with learning burnout as well as the edges within the latter factor. Based on a network analysis of the relationships among ID susceptibility, inhibition, and negative consequences, the current findings support dual-system theory. These results can serve as a reference for attempts to prevent and intervene in ID with the goal of promoting the healthy growth of adolescents.

BAS drive might be a susceptibility factor for the ID network

This study found that the central node in the network was BAS-drive. Drive reflects the tendency to seek out and engage in potentially rewarding activities, thereby emphasizing the motivation to achieve reward [70]. The cognitive behavioral perspective on ID suggests that the high reward-seeking motivation of individuals with ID lies at the core of the development and maintenance of their addiction [71]. The internet world includes various new and different contents (e.g., online gaming positive incentives) that can enable adolescents, especially those with higher sensitivity to reward dependence and novelty processing, to seek abundantly available rewarding stimuli in a convenient manner [72], thus generating excessive online-seeking motivation. Simultaneously, the impairment of individuals' inhibition control makes it difficult for them to control this seeking motivation [60, 71], thus leading to ID. Previous studies have found that hyperreactivity in the prefrontal region of individuals with higher BAS indicates dysfunction of the reward circuit [31]. Drive increases the level of mobile phone dependence [73, 74] and is significantly correlated with activity in the ventral striatum [70, 75], a region which is associated with reward.

Self-control as a protective factor in the network against ID among adolescents

Self-control plays a regulatory role throughout the entire network because it could decrease learning burnout and restrain maladaptive fun-seeking among adolescents. According to previous findings, students with higher levels of self-control exhibit less fun-seeking [76]. However, high levels of fun-seeking among individuals can decrease their self-control, thus leading to an increased risk of dependence [51, 74]. Individuals with poor self-control find it difficult to downregulate their negative emotions, thereby reducing their pursuit of positive emotions [77]. Studies of teenagers have found that adolescents with poor self-control invest less effort into learning and report that they are denied more often [78]. Their lower level of positive emotions and higher level of negative emotions, in turn, reduce their self-control ability [79], thus leading to the emergence of a vicious cycle. In addition, self-control is correlated with burnout. According to the self-regulation intensity model of self-control, an individual's ability to exert self-control is limited, and any self-control task consumes self-control resources [80]. When individuals become tired physically, they need more self-control resources to regulate their current state [81]. Due to resource depletion, their ability to exercise self-control becomes less effective, leading to various negative outcomes, such as dependence to the online world. In summary, self-control is closely related to fun-seeking as well as emotional and physiological exhaustion, and the disruption of this balance increases the risk of ID.

However, in the network of adolescent dependence, self-control cannot be identified simply as a defensive mechanism. Although previous mainstream literature has consistently claimed that self-control plays a protective role with regard to ID [23, 82], this factor is more complex and is positively correlated with drive. Accordingly, the higher an individual's self-control ability is, the higher the individual's drive for rewards. One possibility is that drive can help individuals continue to pursue their desired goals [64], while self-control helps individuals achieve those goals with high probability, as their efforts are more effectively aligned with the goals in question. This situation may promote a mutual influence between self-control and drive: as a result of high self-control and drive, individuals persistently eliminate other distractions, thus enabling them to fulfill their higher needs or seek high-level rewards [78], including continuous internet use or online gaming. However, in the long term, teenagers drive themselves to seek the internet and mobilize their cognitive control resources to focus on the online world, thereby neglecting the development of their learning and social abilities. This persistent pursuit of goal-oriented behavior may thus be maladaptive. Another way in which the current research expands our understanding of the context of adolescent with ID is by revealing the exacerbating effect of learning burnout on ID.

The exacerbating effect of academic burnout on ID among adolescents

The current research revealed that learning burnout, including emotional and physical exhaustion, exhibited strong positive connections with ID and punishment sensitivity. The connection between emotional exhaustion in

the context of learning burnout and ID was the strongest across the entire network, as has been confirmed by previous studies [83–85]. Individual with ID often experience anxiety, depression, and other moods [86, 87]. In the real world, members of these groups lack support from their parents and peers, and their negative emotions cannot be resolved [43, 88], which may lead to self-denial and dissatisfaction, leading to emotional exhaustion. The internet provides such individuals with a way to escape the pressures of reality and alleviate their negative emotions, thus making it easier for them to become addicted to the online world [39].

In addition, physiological exhaustion in the context of learning burnout was related to punishment sensitivity. Adolescents are undergoing a critical period of rapid physical and mental development [89]. During this period, adolescents experience rapid brain development [90], hormonal and morphological changes linked to puberty [91], a positive sense of self [92], and significant academic pressure [93]. Various factors may make them more sensitive to negative external stimuli (such as criticism from their parents, teachers, etc.). This negative information depletes the physiological energy and material resources that students need to continue learning, thus leading to learning burnout. Another possibility is that adolescents who are excessively addicted to the online world are prone to problems such as obesity, back pain, and neck pain as well as poor physical fitness [94], thus making them more prone to physiological exhaustion. Simultaneously, adolescents with ID exhibit narrow attention [95], feel afraid of being punished when they make mistakes [96], and are susceptible to aggressive behavior [82].

Specific network features of ID

Current research has identified structural variations in the network between ID group and IND group. A stronger correlation between punishment sensitivity and lack of learning self-efficacy was observed in ID group and IND group. This may be due to the heightened anxiety and distress experienced by internet-dependent, punishment-sensitive teenagers when confronted with adverse academic outcomes [97]. Such experiences could prompt them to ascribe academic pressures to their perceived lack of learning abilities, consequently diminishing their learning self-efficacy [98, 99]. Furthermore, the negative correlation between nodes LBS2 and LBS4 was also stronger in the ID group relative to IND group. We speculate that, on the one hand, adolescents with low learning self-efficacy are more prone to feelings of frustration and helplessness when engaging with academic tasks. These negative emotions can deplete their psychological resources, resulting in physical fatigue [100]. On the other hand, internet dependent teenagers often exhibit compromised physical health [19, 101, 102], making them more susceptible to feelings of burnout and lethargy when tackling academic challenges, thereby further eroding their learning self-efficacy. Additionally, the positive correlation between nodes LBS3 and LBS4 was more robust in IND group than in ID group. This suggests that individuals with ID may be more inclined towards social withdrawal [103], thereby shunning interactions with teachers and other forms of communication in school life.

Practical implications

This study provides guidance and strategies for the prevention of ID among adolescents as well as interventions aimed at addressing this issue. Drive, as a core node in the network, indicates that we must pay attention to adolescents with high scores on drive traits and keep them away from the temptations of the internet. Simultaneously, cognitive re-evaluation and other forms of intervention training should be used to reduce their drive with regard to the internet [104, 105]. Second, it is necessary to strengthen the cultivation of self-control among adolescents by providing students with self-control training courses [106] or cognitive control training [107, 108] to ensure that they can cope with various emotional, academic, and social pressures more effectively, thereby reducing ID. Third, learning burnout is both a consequence and an accelerator of ID. We should focus on the mental health and physical fitness of teenagers, encouraging them to participate in physical exercise and reduce their online time and encouraging them to engage in frequent discussions with peers, parents and teachers to reduce the risk of ID [46, 88]. Last, considering the differences between the two networks, we can address ID in adolescents through the following three aspects: Firstly, foster positive guidance and establish sensible goals: by providing positive guidance, we can help teenagers recognize the detrimental effects of ID and increase their awareness of its negative consequences. Setting attainable learning objectives enables them to boost their confidence and learning self-efficacy through constructive feedback [109], thereby reducing their reliance on the internet. Secondly, enhance learning techniques and physical fitness: encourage teenagers to embrace diverse learning approaches to spark interest and boost efficiency [110]. Concurrently, adolescents should adhere to a consistent schedule and engage in physical activities to bolster their physical health and alleviate stress. Thirdly, strengthen teacher-student interaction: by organizing collective activities, we can foster emotional exchanges emotional communication between teachers and students, as well as among classmates [111], assisting teenagers in overcoming the confines of internet and enjoying a healthy school life.

Limitations and directions for future studies

The current study employs a cross-sectional design [57, 112] and can only explore the correlations among ID, behavioral approach/avoidance systems, self-control, and learning burnout; hence, no inferences could be drawn regarding the causal relationships among these variables. Future longitudinal studies are warranted to explore the causal relationships between these factors and ID.

In addition, the research subjects investigated in this study are adolescents, who have a relatively mature reward motivation system but an incomplete cognitive control system [20, 21]. The conclusions of current research on adolescent ID networks may not necessarily be generalizable to children or adults. Future research can conduct a network analysis of the development process leading from children to adolescents to adults [113] or use recursive network methods based on time series data [114] to reveal the characteristics and developmental patterns associated with ID across different age groups.

Third, the study did not strictly match participants in the ID and IND groups based on factors such as age, gender, and educational level. Although this approach enhances the ecological validity of the research, it may potentially limit the ability to draw definitive conclusions about the specific effects of ID [115, 116]. Therefore, future research is recommended to control for these potential confounders and further validate the findings of this study.

Last, the current study explores the mechanisms of reward, cognitive control, learning burnout, and ID among Chinese adolescents. Given the emphasis on high competition and high standards in Chinese education [117], the parenting styles characterized by overprotection or neglect [118], the societal high expectations for adolescent success [119], and the widespread use of smartphones and the internet [40], it remains to be investigated whether the current findings can be generalized to different cultural contexts. Further research is needed to address this question.

Conclusion

The relationships among adolescents' ID, reward, cognitive control processing and learning burnout were examined using network analysis. The core influencing factor of the whole network is drive, and the protective factor is self-control. Emotional exhaustion and physiological exhaustion in the context of learning burnout are related to ID and punishment sensitivity, respectively. In conclusion, this study provides insights into the complex mechanisms underlying ID among adolescents from the perspective of the network relationship between core influencing factors and negative consequences. The current findings support dual-system theory and can serve as a reference for early warning and interventions aimed at addressing ID among adolescents.

Supplementary Information

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Supplementary Material 1

Author contributions

Haotian Wu: contributed to conceptualization, data curation, formal analysis, and Wrote the original draft; Guangteng Meng: contributed to methodology, visualization, and formal analysis; Lingxiao Wang: contributed to conceptualization; Jing Xiao: contributed to investigation; Kesong Hu: reviewed and improved the final form of the manuscript; Qi Li: contributed to conceptualization, funding acquisition, resources, supervision, reviewed and improved the final form of the manuscript. The author(s) read and approved the final manuscript.

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Data availability

The datasets used and/or analyzed during the current study available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

The study procedures were carried out in accordance with the Declaration of Helsinki. Ethical approval was obtained from the Ethics Committee of Capital Normal University. Before the start of the survey, participants and their guardians gave informed consent.

Consent for publication

Not Applicable.

Competing interests

The authors declare no competing interests.

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