Unpacking Associations between Mood Symptoms and Screen Time in Preadolescents: a Network Analysis

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Abstract

Mounting evidence highlights the link between screen time and adolescent mood problems. However, there are several short-comings to the extant literature: (1) this link is underexplored in preadolescents, (2) most existing studies look at mood problems using categorical diagnoses rather than from a symptom-level perspective, despite the heterogeneity within mood disorders, (3) few studies have simultaneously examined the links of mood symptoms with different types of screen time, and (4) family/child-level factors that have shown links to youth psychopathology are not typically considered. This study, for the first time, examined the relationships of mood symptoms with different types of screen time, while accounting for theoretically important factors— parental monitoring and the behavioral inhibition/activation systems (BIS/BAS)—in preadolescents aged 9 to 10 from 9986 families participating in the Adolescent Brain and Cognitive Development Study. Using mixed graphical models, we found that screen time involving age-inappropriate content was stably and significantly associated with various elevated mood symptoms, independent from other types of screen time, BIS/BAS, and parental monitoring. Additionally, age-inappropriate screen time was associated with increased overall symptom connectivity. Further, preadolescents engaged in high levels of age-inappropriate screen time reported different symptom profiles (i.e., differences in symptom centralities) from common pediatric mood problems. Our findings underline the multifaceted role (i.e., direct associations with symptoms, a moderator for symptom relationships, associations with distinct symptom profiles) of age-inappropriate screen time in preadolescent mood problems. These findings serve as foundations for future research that may facilitate early detection of preadolescents at risk of mood problems.

Keywords Screen time · Mood · Depression · Mania · Preadolescent · Network analysis

Prolonged recreational screen time in the younger generation has attracted substantial research attention regarding its potential impacts on mood problems. Recent studies found an association of prolonged screen time with a higher risk of depression in adolescence (for reviews, see Costigan et al. 2013; Keles et al. 2020) and this relationship appears to be reciprocal (Houghton et al. 2018). The relationship of screen time with other mood problems are relatively underexplored. Only a few studies showed that screen time was associated with other mood problems, such as irritability (Marques et al. 2015),

anger (Anderson et al. 2017), emotional instability (Twenge and Campbell 2018), and probable bipolar disorder (Park et al. 2013). Overall, recent research suggests screen time as a potential correlate or risk factor for various mood problems.

Despite mounting evidence, considerable uncertainty in the relationships of screen time to childhood mood problems remains. Systematic reviews found mixed results across studies, with some demonstrating positive relationships between screen time and mood disorders, but others demonstrating insignificant or even negative relationships between the two (e.g., Costigan et al. 2013; Keles et al. 2020). A recent secondary analysis showed that screen time only explained 0.4% of the variance in adolescent well-being, including depression as an indicator, although this study did not include pre-adolescent children (Orben and Przybylski 2019). Overall, researchers agree that the relationship between screen time and mood disorders are more complicated than a dichotomous indication as to whether a meaningful relationship exists or not; however, few studies have aimed to develop more nuanced models to disassemble the complexity. This limited progress may be due

to the reliance on conventional statistical methods derived for low-dimensional multivariate data with low applicability for a high-dimensional system. Therefore, screen time- and mood problem-related studies have excluded many theoretically important components from their research designs.

First, most studies have neglected differences in *types* of screen time. They either measured screen time based on mixed non-specific types of screen-based activities or one specific activity (e.g., time spent on social network sites). Studies that collapsed across diverse types of screen time (e.g., Maras et al. 2015, where hours/day of TV, video games, and computer were combined to form a single "screen time" variable) were able to demonstrate only non-specific associations between screen time and mood problems. However, different types of screen time appeared to have variable associations with mood problems in different populations. It is suggested that different types of screen time be measured separately (Starcevic 2013; van Rooij et al. 2017). While studies focusing on one specific type of screen time may be able to address the idiosyncratic association with mental health problems, they cannot account for the confounding effects of other types of screen time. Therefore, models incorporating separately measured, common types of screen time may clarify complexities in screen time-related mood problems.

Second, screen time-related studies often used categorical depression diagnoses as the outcome variable of interest (Costigan et al. 2013; Keles et al. 2020; Lam 2014). Most measures of categorical depression diagnoses are based on either threshold scores, classifying individuals as "healthy" or "depressed," or the total number of reported symptoms, indicating severity. However, depression is highly heterogeneous in clinical presentations (Østergaard et al. 2011) and symptom trajectories (Wickrama and Wickrama 2010; Yaroslavsky et al. 2013). Depressive symptoms are non-additive regarding functional impairment (Fried et al. 2015). Additionally, various depressive symptoms may relate differently to screen time-related mood problems (Lemola et al. 2014). Further, as depression is defined as a mutually exclusive category from the other mood disorders in the *DSM-5*, hallmark symptoms of other mood problems, such as irritability, anger, and mood instability are relatively under-explored in relation to screen time activities despite their frequent co-occurrence with depressive mood (Mayes et al. 2015; Safer 2009). The use of categorical mood disorders, despite its convenience, has impeded researchers from obtaining a holistic understanding of screen time-related mood problems in youth.

Third, the screen time literature has primarily focused on teenagers and disregarded younger children, resulting in a significant gap in our understanding of the relationships between screen time and mood problems in adolescent versus pre-adolescent youth. This discrepant focus contrasts with digital user data: Per a 2017 report, children aged 2 to 11 had *higher* weekly time spent on digital devices than teenagers aged 12 to 17 in modern U.S. society (The Nielsen Company 2017a). Additionally, children mostly acquire their first service plan on smartphones in pre-adolescence (The Nielsen Company 2017b). The other reason for less attention paid to children in screen time-related studies may be due to a lower prevalence of diagnosable mood disorders in this age group (Kessler et al. 2001). However, subclinical symptoms are common in pre-adolescent youth; are associated with significant psychosocial impairment (Angold et al. 1999; Carlson and Kashani 1988); and confer substantial risk for future mood disorder onset (Angst et al. 2000). Further, younger age is shown to be a risk factor associated with increased screen time-related internalizing disorders (Tsitsika et al. 2014). From an early detection and prevention standpoint, it is critical to investigate the relationships between different types of screen time and mood symptoms in preadolescents.

Lastly, few studies have incorporated child- and family-level factors related to childhood mood problems. Factors such as *childhood personality* and *parenting styles* may be important to incorporate into models linking screen time to mood problems in youth (for a review, see Keles et al. 2020). For instance, the behavioral inhibition and activation systems (BIS/BAS) are personality traits related to both screen addiction and mood problems. Specifically, higher BIS and BAS fun-seeking levels are both associated with increased screen addiction (Meerkerk et al. 2010; Park et al. 2013; Yen et al. 2009); higher BIS and lower BAS levels are associated with increased depression; and higher BAS levels are associated with increased hypomania/mania (Alloy and Abramson 2010; Johnson and Carver 2006; Kasch et al. 2002). Additionally, parental monitoring is a well-known environmental factor viewed as a critical deterrent of risky behaviors in preadolescence and is, therefore, protective against future psychiatric problems, including mood disorders (Hamza and Willoughby 2011; Snyder et al. 1986; Yu et al. 2006). Parental monitoring is shown to reduce screen time and exposure to media violence in preadolescents (Gentile et al. 2014). It is also bi-directionally associated with adolescent depression even after controlling for age and social-economic status (Bean et al. 2006; Hamza and Willoughby 2011; Yu et al. 2006). In order to parse the unique links of screen time with various mood problems, it is therefore critical to account for the ways in which child- and parent-level factors may relate to children's screen time and mood difficulties.

To address these gaps in the literature, the current study required statistical methods featuring applicability for high-dimensional multivariate data. Network psychometrics possess unique advantages in examining relationships in complex systems. From a network perspective, mental disorders are viewed as complex and dynamic networks of symptoms that interact with each other (Borsboom 2017; Eaton 2015; McNally 2016; McNally et al. 2015). Recent studies have

further expended the use of symptom networks by including posited risk factors, such as stress, into the network system (Fried et al. 2015). One study has investigated the temporal relationship between social media use and depressive symptoms (Aalbers et al. 2018). In light of the expansion in the use of network models, the current study adopted a similar framework to address the aforementioned issues in research design regarding screen time and its associated mood problems.

This study investigated relationships of different types of screen time with mood symptoms in preadolescents using a network approach, accounting for theoretically important personality- and environmental-level factors (BIS/BAS and parental monitoring). As previous studies indicate that sex effects varied among the associations of different types of screen time with mood problems (Blomfield Neira and Barber 2014; Gonzálvez et al. 2017), we also examined sex differences in these associations. We hypothesized that all types of screen time would be positively associated with mood symptoms, independent of the BIS/BAS and parental monitoring. Given the exploratory nature of this study, we did not have a priori hypotheses regarding sex differences in associations between different types of screen time and mood symptoms. This study may facilitate early detection of screen time-related mood problems by expanding our knowledge on the relationships between specific types of screen time and individual mood symptoms in preadolescents.

Method

Participants

This study utilized the baseline data from the Adolescent Brain and Cognitive Development (ABCD) Study, Curated Annual Release 2.0 ($N = 11,875$). The ABCD Study is designed to follow youths recruited at age 9 and 10 ($M = 9.91$, $SD = 0.62$) from 9987 families into their adolescence/young adulthood. The first wave was fielded in 2016–2018, where females composed 48% of the child sample. The baseline race/ethnicity composition was 49% non-Hispanic white, 17% non-Hispanic black, 23% Hispanic, 5% Asian, and 5% others. The ABCD study collected a wide variety of participant data, including brain imaging, biomarkers, cognitive functioning, mental and physical health, family history, and environmental factors. For details regarding the data collection process, please see Barch et al. (2018) and Garavan et al. (2018).

Most ABCD research sites relied on a central Institutional Review Board (cIRB) at the University of California, San Diego for ethical approval of the research protocol, with the exception of the site at Washington University in St. Louis utilizing their local IRB approval. Informed consent and assent of parents and children were obtained prior to the baseline

assessment. All sites have complied with the ethical regulations during data collection, release, and analysis (Auchter et al. 2018). De-identified ABCD data can be accessed by NIH-recognized research institution with Federal-wide Assurance. The current use of the ABCD data for secondary analysis is exempt from IRB review, according to the IRB of Stony Brook University.

Assessments

Mood Symptoms Mood symptoms were assessed with the computerized *Kiddie Schedule for Mood Disorders and Schizophrenia for DSM-5* (*K-SADS-5*; Kaufman et al. 2013). The youth version of K-SADS-5 was initially designed for children aged 12 or older. However, according to the statement from the ABCD workgroup (Barch et al. 2018), the workgroup has confirmed with Kaufman (the author of the K-SADS-5) that the youth version could work well in youth starting at age 9–10 with staff support on assessment. Mood symptoms assessed in the K-SADS-5 screening interview included: *depressive mood*, *anhedonia*, and *irritability* for depression, and *anger*, *decreased need for sleep*, *elevated mood* and *increased sexuality* for mania. All symptoms were binary (0 = absent, or 1 = present), and all youths in the sample completed each screening question. The computerized K-SADS-5 has shown promising psychometric properties and validity in assessing mood disorders (Townsend et al. 2020).

Screen Time The ABCD assessed screen time by combining content from two questionnaires that are associated with behavioral problems and poor school performance (Hull et al. 2014; Sharif et al. 2010). Common types of screen time reported by children included: watching television or movies, watching videos, playing video games, visiting social media sites, texting, and video chatting. Screen time on a typical weekday and weekend day were measured separately. The scoring method was as follows: 0 = no usage; 0.25 = less than 30 min; 0.5 = 30 min; 1 = 1 h; 2 = 2 h; 3 = 3 h; and 4 = more than 4 h per day. Average daily screen time was computed as the weighted mean of the screen time on a typical weekday (multiplied by 5/7) and weekend day (multiplied by 2/7), rounded to the nearest integer. The assessment also included two age-inappropriate screen time behaviors, namely "playing mature video games" and "watching R-rated movies." The frequencies of these two types of screen time were rated as: 0 = never; 1 = once in a while; 2 = regularly; 3 = all the time. Although scaling methods differed, the mean values and distributions across different types of screen time were similar, warranting comparability. (For the comparison of distributions, please see S1 in Supplementary Materials.)

Behavioral Inhibition and Activation Systems The BIS/BAS scale is a 24-item child self-report questionnaire measuring

two motivational systems, viewed as dimensions of childhood temperament: the behavioral inhibition system (BIS) and the behavioral activation system (BAS; Carver and White 1994). The BIS subscale is designed to reflect avoidance motivation of aversive outcomes (7 items; $\alpha = 0.74$; e.g., "Criticism or scolding hurts me quite a bit.") The BAS subscale reflects goal-oriented drive (BAS-D, 4 items; $\alpha = 0.76$; e.g., "When I want something I usually go all-out to get it."), fun-seeking (BAS-FS; 4 items; $\alpha = 0.66$; e.g., "I crave excitement and new sensations."), and reward responsiveness (BAS-RR; 5 items; $\alpha = 0.73$; e.g., "It would excite me to win a contest."). Mean scores on each subscale ranged from 1 (*very true for me*) to 4 (*very false for me*), with higher scores indicating higher levels of that dimension. We used the average scores of each of the four dimensions (i.e., BIS, BAS-D, BAS-FS, BAS-RR) for present analyses. As mentioned in the introduction, the BIS/BAS scales are related to increased mood problems and screen addiction (Alloy and Abramson 2010; Johnson and Carver 2006; Kasch et al. 2002; Meerkerk et al. 2010; Park et al. 2013; Yen et al. 2009).

Parental Monitoring The ABCD research team adapted the *Parental Monitoring Survey* in the article by Chilcoat and Anthony (1996). The current survey consists of five items on a 5-point Likert-type scale ranging from 1 (*never*) to 5 (*always or almost always*), including questions such as "How often do your parents/guardians know where you are?" and "In an average week, how many times do you and your parents/guardians, eat dinner together?" Items were averaged, and the mean score was used for the current analyses, as the mean of child perceived parental monitoring has been shown to be associated with elevated risk of mental problems in prior work (Chilcoat and Anthony 1996; Zucker et al. 2018).

Network Analysis

We estimated the network structure of the six mood symptoms (except increased sexuality because none of the children endorsed this symptom), the eight types of screen time, the four BIS/BAS dimensions, and the levels of parental monitoring. To avoid violations of the model assumption of node independence, we only used symptoms in the screening interview to conduct network estimation without the inclusion of symptoms assessed afterward. We estimated the networks of the full sample and subsamples by sex. The networks are undirected due to the cross-sectional nature of the data. Such networks contain nodes representing variables of interest (i.e., here, mood symptoms; exposure to different types of screen time; and mean levels of parental monitoring and BIS/BAS scales) as well as edges representing conditional dependencies among nodes (i.e., the relationship between any two nodes while partialling out effects of the other nodes).

To incorporate different types of variables (e.g., continuous, count, and binary variables), we employed mixed graphical models (MGM) via exponential families (Yang et al. 2014) with the *R* package *mgm* (Haslbeck and Waldorp 2015). Such models allow us to specify the distribution of each node in the network. We used Quantile-Quantile (Q-Q) plots to examine the distribution of each variable (other than binary symptoms) before model specification (for the results, please see Fig. S1 in the Supplementary Materials). We specified continuous variables approximating to a Gaussian distribution (e.g., the BIS/BAS dimensions) as Gaussian variables, count variables (e.g., screen time) approximating to a Poisson distribution as Poisson variables; and mood symptoms as binary variables. Parental monitoring, a continuous variable, showed a significant negative skew. We therefore applied a cubic transformation before specifying it as a Gaussian variable.

Our data had a nested structure (with children within families), and so families were the basic unit of sampling. If more than one child in a family participated in the study, we randomly sampled only one child at a time. The final edge weights were averages across 1000 times bootstraps with replacement (N_{family} - 1). We applied l1-regularization (LASSO) and cross-validation to control for spurious relations in the MGM models (Chen et al. 2014; Yang et al. 2014). We used simulated random networks to test for significance (Cf. Su et al. 2017) and the bootstrap method developed by Epskamp et al. (2018) for edge-weight stability (see S1 in Supplementary Materials for detailed methods). Additionally, we conducted a sensitivity analysis to examine the relationship of node selection to network stability (see S2 in Supplementary Materials for detailed methods). Further, sex differences in edges of mood symptoms and screen time were examined by permutation tests that compared edge weights of interest (i.e., here, the relationships of screen time with mood symptoms; van Borkulo et al. 2017) with the *R* package *NetworkComparisonTest* (van Borkulo et al. 2019).

Finally, we selected types of screen time that were shown to have significant and stable patterns of relationships with mood symptoms to conduct further analysis regarding the overall symptom connectivity and respective symptom centrality. The procedure was adapted from the method described by Lin et al. (2020). We measured the overall symptom connectivity based on the sum of edge weights (including non-absolute negative values) and symptom centrality based on the node strength (i.e., the sum of weights of edges connected to the node). We estimated 1000 bootstrapped symptom networks for individuals at each level of selected type of screen time. To compare symptom connectivity and centrality across levels, for each selected type of screen time, we used the smallest family number in one level minus one as the bootstrapping sample size for all levels. The methods of network estimation and sampling were identical to those described above. Finally, we conducted multiple regressions of

the overall symptom connectivity and symptom centrality on the levels of screen time, accounting for edge or node differences, based on 1000 bootstrapped networks of each screen time level.

Results

Descriptive Statistics

Table 1 contains the descriptive statistics of the full sample and two subsamples (divided by sex) for all the measured variables. To examine sex differences, we conducted multiple *t*-tests; Table 1 includes Bonferroni adjusted *p* values. Sex differences emerged in the prevalence of mood symptoms, where more males than females reported anhedonia and decreased need for sleep. Sex differences also emerged in screen time: Females reported spending more time on texting and visiting social network websites than males, whereas males reported watching videos and playing videogames more frequently than females. Males also reported more frequent exposure to age-inappropriate content (e.g., mature video games or R-rated movies) than females. Females also reported higher

levels of BIS and parental monitoring, but lower levels of BAS, than did males—consistent with past research on these constructs (Borawski et al. 2003; Pagliaccio et al. 2016; Vermeersch et al. 2009).

Network Analysis

The three networks in Fig. 1 demonstrate the conditional dependency of mood symptoms with screen time variables when accounting for the BIS/BAS and the levels of parental monitoring for the full and subsamples by sex. To facilitate visual comparisons, the plotted network layouts (i.e., positions of nodes) of the subsamples were identical to the network layout of the full sample. The edge weights in each network were computed based on the average of 1000 bootstrapped networks. Across the bootstraps, the stability of absolute/rank-order edge weights were 0.88/0.8, 0.79/0.71, and 0.83/0.75 for the full, female, and male samples, respectively. Further, we examined the stability of edge weights in relation to sample size. The mean correlations of the absolute and rank-order edge weights between the full and smaller subsamples across 1000 bootstraps could remain above 0.8 and 0.7, respectively, when the sample size dropped to 40% of the total sample. Further, the sensitivity

Table 1 Descriptive statistics and gender differences in variables

Variables	Full sample			Females	Males	Adjusted p
	M (SD)	Min	Max	M (SD)		
Symptoms						
Irritability	0.03 (0.18)	0	1	0.03 (0.17)	0.04 (0.19)	0.655[***]
Depressive mood	0.02 (0.15)	0	1	0.02 (0.15)	0.02 (0.15)	> 0.999[***]
Anhedonia	0.05 (0.21)	0	1	0.04 (0.20)	0.05 (0.23)	0.038*[***]
Elevated mood	0.02 (0.15)	0	1	0.02 (0.15)	0.02 (0.15)	> 0.999[***]
Anger	0.02 (0.14)	0	1	0.02 (0.13)	0.02 (0.15)	0.384[***]
Decreased need for sleep	0.02 (0.15)	0	1	0.01 (0.12)	0.03 (0.18)	< 0.001[***]
Screen time						
TV/movie	1.22 (1.12)	0	4	1.21 (1.12)	1.23 (1.12)	> 0.999[***]
Video	0.89 (1.21)	0	4	0.8 (1.17)	0.98 (1.24)	< 0.001[***]
Video game	0.93 (1.19)	0	4	0.57 (0.97)	1.26 (1.27)	< 0.001[***]
Texting	0.14 (0.55)	0	4	0.16 (0.60)	0.12 (0.51)	0.002[***]
Social media	0.08 (0.43)	0	4	0.1 (0.46)	0.07 (0.39)	0.002[***]
Video chatting	0.12 (0.50)	0	4	0.13 (0.52)	0.11 (0.48)	0.102[***]
Mature video game	0.57 (0.87)	0	3	0.28 (0.61)	0.83 (0.99)	< 0.001[***]
R-rated movie	0.38 (0.64)	0	3	0.32 (0.60)	0.43 (0.67)	< 0.001[***]
Covariates						
BIS	9.51 (3.75)	0	21	9.85 (3.78)	9.2 (3.70)	< 0.001[***]
BAS-RR	4.14 (3.06)	0	12	3.84 (2.99)	4.42 (3.10)	< 0.001[***]
BAS-D	11.00 (2.92)	0	15	10.87 (2.93)	11.12 (2.90)	< 0.001[***]
BAS-FS	5.71 (2.64)	0	12	5.55 (2.63)	5.85 (2.65)	< 0.001[***]
Parental monitoring	21.88 (2.76)	0	25	22.35 (2.53)	21.45 (2.84)	< 0.001[***]

[*] =p value < 0.05; [**] = p value < 0.01; [***] = p value < 0.001

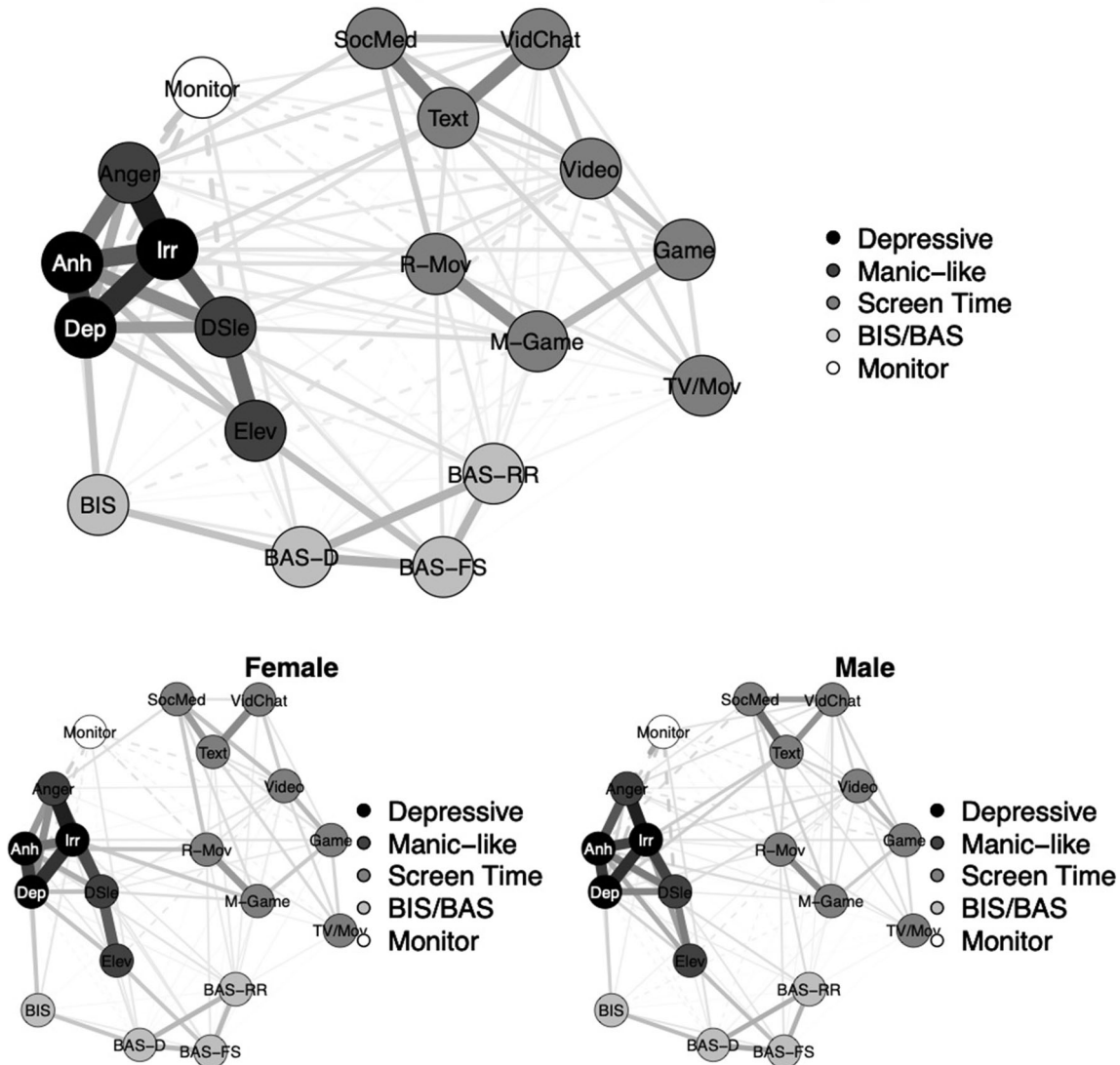## The Relationships of Screen Time with Mood Symptoms

Fig. 1 The conditional dependence of mood symptoms with screen time variables when accounting for the BIS/BAS and levels of parental monitoring. The width of an edge indicates the strength of a relationship. A blue line (or a solid line in the black and white version) indicates a positive relationship, while a red line (or a dashed line) indicates a negative relationship. Irr = irritability; Dep = depressive mood; Anh = anhedonia; Elev = elevated mood; DSle = decreased need for sleep; TV/Mov = watching TV or movies; Video = watching videos; Game = playing video games; Text = texting; SocMed = visiting social media websites; VidChat = video chatting; M-Game = playing mature video games; R-Mov = watching R-rated movies

analysis indicated little impact of nose selection on the overall network stability or relationships between screen time and mood symptoms (for detailed results, see S2 in Supplementary Materials). Overall, these numbers indicate a fairly high degree of stability in the edge weights of our results.

The strongest associations observed in the networks were among the mood symptoms themselves. Edges of mood symptoms with screen time were weaker and with variable selection rates (i.e., rates of having non-zero coefficients after the shrinking process of LASSO) across bootstraps. However, specific associations did emerge: screen time on age-inappropriate contents, such as mature video games or R-rated movies, was significantly (i.e., passing the simulation significance test) and

stably (i.e., the CIs did not contain opposite signs) associated with various mood symptoms, both in the total sample and in females and males separately. Children reporting increased time playing mature video games were more likely to report irritability, depressive mood, anhedonia, and decreased need for sleep. Likewise, children who reporting watching more R-rated movies were more likely to report irritability, depressive mood, anhedonia, and anger, but less elevated mood. Further, the permutation-based network comparison tests suggested that time spent watching R-rated movies was associated with anhedonia in females, but not males.

Edges of mood symptoms with common screen time without specifying age restrictions (i.e., watching television or

movies, watching videos, playing video games, visiting social media sites, texting, and video chatting) lacked a consistent pattern. None of the mood symptoms were associated with all types of common screen time, and none of these types of screen time showed significantly and stably positive associations with more than two mood symptoms. Some types of common screen time showed mixed relationships with mood symptoms. For example, playing video games was positively associated with irritability, decreased need for sleep, but negatively associated with anger and depressive mood. Notably, elevated mood was generally negatively associated with most types of screen time. Further, the permutation-based network comparison tests suggested no sex-difference in the relationships of mood symptoms with common screen time. Overall, screen time on age-inappropriate, but not non-age restricted, content showed a consistent pattern of relationships with mood symptoms. For detailed characteristics of each edge, please see Table S1 in Supplementary Materials.

We further conducted a series of network and regression analyses examining the association between screen time on mature video games and R-rated movies with the overall network connectivity and respective node strength. The results of multiple linear regressions based on bootstrapped networks showed that the increase of screen time on mature video games and R-rated movies were both significantly associated with the increase of the overall network connectivity (mature video games: $b = 0.02$, $t = 9.25$, $p < 0.001$; R-rated movies: $b = 0.05$, $t = 17.34$, $p < 0.001$) with an R^2 of 0.25 and 0.19, respectively, after accounting for edge differences (i.e., all mood symptoms were increasingly tightly connected to each other as *mature video game time* or *R-rated movie watching time* increased).

Figure 2 demonstrates the associations of screen time with respective node strength (i.e., the sum of weights of edges connected to the node). The results showed that irritability was the central symptom of general preadolescent mood disorders. For individuals with higher levels of screen time on mature video games, the node strength of irritability, elevated mood, and decreased need for sleep were significantly higher, but the node strength of depressive mood was significantly lower. For individuals with higher levels of screen time on R-rated movies, the node centrality of anhedonia, anger and decreased need for sleep were significantly higher. Further,

Fig. 2 The association of respective node strength (i.e., symptom centrality) with screen time on mature video games and R-rated movies. Note that the sample size used for estimating networks of the two screen time variables were different, and therefore, readers should not compare the node strengths in networks of different screen time variables directly
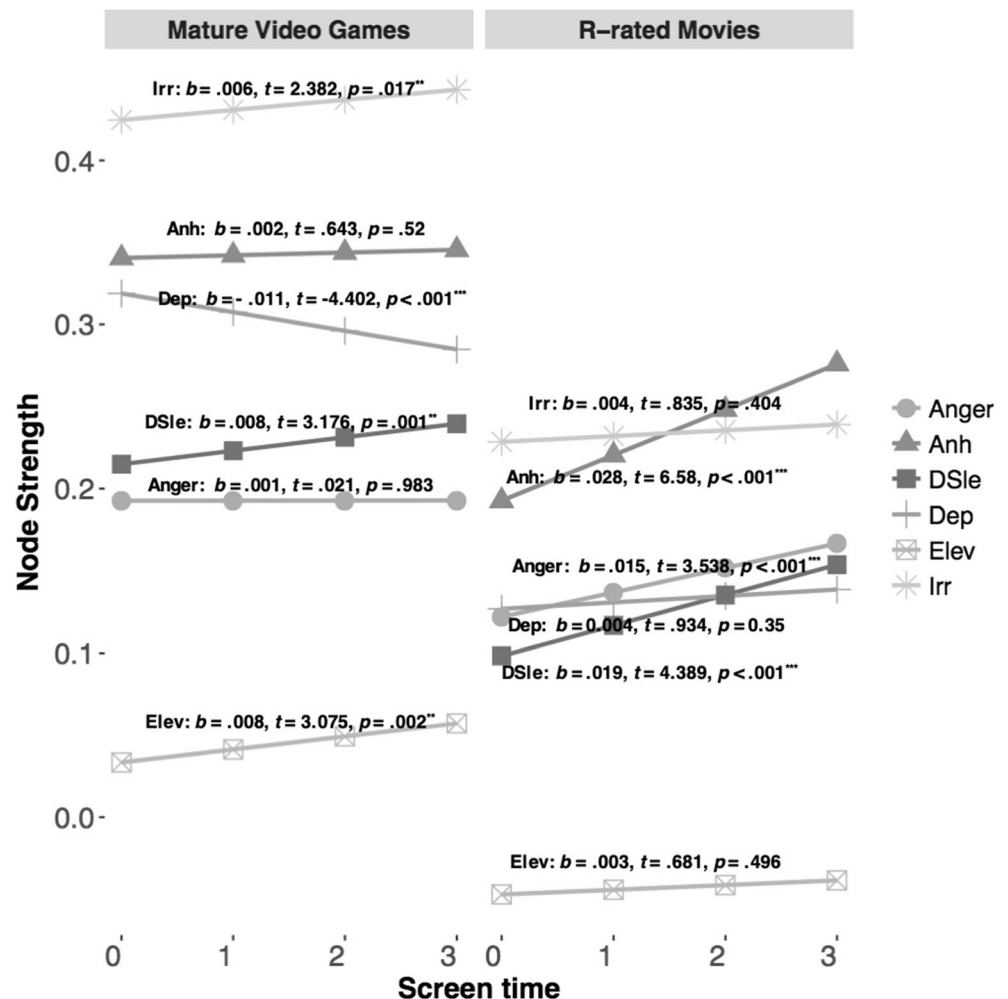
the centrality of anhedonia in preadolescents with extensive exposure to R-rated movies was estimated to be even higher than the centrality of irritability.

Discussion

Summary of Findings

Results of network analyses using the ABCD data of preadolescents from 9987 families suggest complex links of screen time with preadolescent mood symptoms after accounting for theoretically important child- and parent-level factors (i.e., BIS/BAS and parental monitoring). We observed a lack of consistent patterns in the relationships of most types of screen time and mood symptoms. However, screen time involving age-inappropriate content was stably and significantly associated with various elevated mood symptoms, such as irritability, depressive mood, anhedonia, anger, and decreased need for sleep, independent from other types of screen time, BIS/BAS, and parental monitoring. Additionally, age-inappropriate screen time was associated with increased overall symptom connectivity. Further, preadolescents engaged in high levels of age-inappropriate screen time reported different symptom profiles (i.e., differences in symptom centralities) from common pediatric mood problems.

Implication of the Primary Findings

To the best of our knowledge, this study is the first to disentangle complex links between different types of screen time and mood symptoms in preadolescence while accounting for theoretically important correlates of preadolescent mood problems. Our models may help contextualize the mixed disorder-level results reported in the literature to date. Because mood disorders are heterogeneous (Østergaard et al. 2011; Wickrama and Wickrama 2010; Yaroslavsky et al. 2013) and various mood symptoms are differentially linked to functional impairment (Fried and Nesse 2015), disorder-level constructs may obscure results in unpredictable ways. Therefore, a finer-grained approach at the symptom level is needed.

At the symptom level, most types of screen time did *not* show consistent relations to mood symptoms when controlling for the shared variance among other types of screen time. Different types of screen time were only weakly associated with one or two elevated mood symptoms. Further, no symptom was commonly associated with all types of screen time. Therefore, when (1) mixing (or not controlling for) different types of screen time and (2) analyzing mood problems at the disorder level rather than symptom level, results may be sensitive to the prevalence of certain screen time behaviors and symptoms in a particular sample. The instability of mixed-screen-time-variable and disorder-level analysis may lead to

mixed results across studies. This study resonates with research highlighting the importance of measuring different types of screen time separately (van Rooij et al. 2017). It also adds to a growing body of research demonstrating that respective symptoms are differently associated with non-symptom variables (Aalbers et al. 2018; Eiko I. Fried and Nesse 2014). This study suggests that greater model complexity, not less, may provide more lucid explanations of the screen time-mood problem link, as has been observed in other areas of clinical science (Fox et al. 2019).

Additionally, our results indicate a crucial role for the content of screen time in preadolescent mood problems. Among all types of screen time, only screen time on age-inappropriate content showed stable relationships with multiple individual mood symptoms. Contrary to some studies that view sleep disturbance as a mediator between screen time and mood problems (e.g., Lemola et al. 2014), we did not observe any single *bridge* node, including sleep disturbance, for age-inappropriate screen time and mood symptoms. This finding is supported by a previous study, in which sleep duration only served as a mediator of screen time to externalizing, but not internalizing, problems in children aged 8 to 12 (Parent et al. 2016). Also note that the current screen time measure included both day- and night-time screen use, while night-time screen use has been particularly suggested to impair sleep (Hale and Guan 2015; Mireku et al. 2019; Vijakkhana et al. 2015).

In addition to the direct associations with mood symptoms, age-inappropriate screen time was also significantly associated with increased overall symptom connectivity, which indicates its potential moderating role on mood symptom relationships. Given the cross-sectional nature of the current data, we do not know if age-inappropriate screen time causes elevated mood symptoms in preadolescents, or vice versa, or both. However, our results suggest that the age-inappropriate screen time is associated with mood symptoms beyond simple linear relationships.

Lastly, our results suggest that preadolescents engaged in higher levels of age-inappropriate screen time may exhibit symptom profiles different from common pediatric mood problems. In line with the literature on pediatric mood disorders Leibenluft et al. 2003; Stringaris 2011), our findings showed that irritability is the central symptom of preadolescent mood problems in the general population. However, for preadolescents with higher levels of screen time on mature video games, the centrality of irritability, elevated mood, and decreased need for sleep increased significantly, while the centrality of depressive mood decreased significantly. For preadolescents with higher levels of screen time on R-rated movies, the centrality of anhedonia, anger, and decreased need for sleep significantly increased. Specifically, for preadolescents report watching R-rated movies "regularly" or "all the time," their anhedonia symptom is estimated to be even more central than irritability. Since external behaviors are more

observable than internalizing symptoms, these findings may facilitate early identification of preadolescents at higher risk of mood problems.

Confounding Variables

Alternations of sleep patterns are indicators of various emotional, behavioral, and neurological problems. However, a self-report assessment may not be adequate to differentiate the causes of sleep disturbance in preadolescents. Even when a measure utilizes subtle wording intended to capture nuance in a construct of interest, children might interpret certain items differently than the measure developers intended. For example, the item "decreased need of sleep" is intended to gauge the presence of mania—but a 9-year-old child might respond to reflect their subjective view that they *generally* do not need much sleep, which is common among children with externalizing problems, ADHD, and autism-spectrum disorder (Henderson et al. 2011; Lycett et al. 2015). Thus, it is questionable if behavioral sleep problems in children reflect an actual decreased need for sleep. Further, shortened sleep time is associated with exacerbated emotional, behavioral problems, and daytime fatigue (Langberg et al. 2020; Pieters et al. 2015; Quach et al. 2018). Without information from a thorough clinical interview, we were unsure to what degree the "decreased need for sleep" item captured mood disturbance instead of other developmental disorders. Note that it is common to all self-report research that a measure may not assess what we think or hope it does.

In line with the previous discussion, a symptom resulting from a specific disorder may lead to broader mood and behavioral problems. Although the current study focused on mood symptoms, comorbidity among mood, behavioral, and neurodevelopmental problems may further complicate the relationships between screen time and individual mood disorder symptoms. For example, one study showed that nighttime social media use in adolescents with ADHD is associated with both sleep problems and comorbid depression (Becker and Lienesch 2018). To further clarify the mood symptom-screen time relationships, it is crucial to incorporate other common behavioral and developmental symptoms as well as cognitive factors (e.g., IQ) that might impact screen time behaviors.

Moderators

Although the sex of a child did not modify the mood-screen relationships in the current study, we wonder if such effect may appear in future studies of adolescents on this topic. The current study focused on a younger sample aged 9–10, but the sex gap of depression appeared around age 11–13 (females are approximately twice as likely as males to have an episode of depression by age 15; Cyranowski et al. 2000).

Similarly, we wonder if the moderating effect of sex on the mood-screen relationships would appear around the same age.

Additionally, in the current study, we observed early differences in screen time behaviors. Females were more engaged in screen time activities featuring social interactions, such as social media, video chatting, and texting, while males were more engaged in videos, video games, mature video games, and R-rated movies. We are inquisitive about the role of screen activities featuring social interactions in adolescent internalizing disorders in females. Further, although we only focused on mood symptoms in the current study, based on males' screen time behaviors and the higher prevalence of externalizing problems in boys (Gutman et al. 2018), we wonder if the "videos-video games-mature video games-r-movies" network would play a unique role in adolescent externalizing disorders in males. These questions require further investigation with an adolescent sample.

Limitations and Future Directions

First, given the cross-sectional nature of the current data, we were neither able to examine the directions of relationships between screen time and mood symptoms nor to differentiate within- from between-person effects. Thereby, one needs to be cautious to apply the current findings to individuals directly. Longitudinal, especially ecological momentary assessment (EMA), research is a promising route to further explore the involvement of screen time in the development of pediatric mood disorders. EMA studies currently endeavor to minimize the burden on participants by condensing assessment to increase assessment validity. The current study provides a good foundation of knowledge to narrow down the target (e.g., focusing on the content of screen time instead of screen time itself) in research design.

Second, the screen time assessment in the ABCD is not entirely consistent. It contains two types of scaling methods for the common and age-inappropriate types of screen time, respectively. Although we have compared the distributions of the variables assessed by the two different methods and found no significant difference in the distributions, we were not able to completely rule out the potential impacts resulting from the measurement difference. We suggest future studies adopting a consistent scaling method in the same questionnaire.

Third, the parental monitoring assessment in the ABCD may not fully capture the construct of "parental monitoring." Dishion and McMahon (1998) defined parental monitoring as "parenting behaviors involving attention to and track of the child's whereabouts, activities, and adaptations (p. 61)." However, most items in the parental monitoring assessment in the ABCD focused on the amount of parental knowledge of children's whereabouts and activities rather than active parental behaviors. As Stattin and Kerr (2000) suggested, the assessment of parental monitoring in future studies should

be reversed for active parental behaviors. Parental knowledge is more strongly associated with child disclosure, and the variation in child disclosure may reflect underlying individual differences (e.g., child personality traits; Eaton et al. 2009), which may be a potential third factor among parental monitoring (knowledge), delinquent behavior (e.g., engaged in age-inappropriate screen time), and mood problems. Additionally, family dynamics as a whole may shape parenting behaviors and children's social-emotional development (Repetti et al. 2015). Thereby, Eaton et al. (2009) suggested incorporating personality traits and the dynamics among parental knowledge, child disclosure, and other family systemic factors to achieve a better understanding of parental monitoring (knowledge) related topics.

Fourth, we only adopted youth-report in the current study. Parents and children tend to provide divergent reports of child internalizing symptoms, with the cross-informant correlations at about 0.2 on average (Comer and Kendall 2004; Edelbrock et al. 1986). Child reports of symptomatology appear to have higher sensitivity, while parent reports have higher specificity (Angold et al. 1987). Additionally, older children are considered to be better informants for internalizing disorders than their parents (Smith 2007), as parents are frequently unaware of "invisible" symptoms their child may be experiencing (e.g., suicidal ideation; Eg et al. 2018). Considering the importance of high-sensitivity, early detection of child mood problems, we relied on youth reports as our information source for this study.

Fifth, to avoid violation of the network assumption of node independence, we only used the mood symptoms from the screening questionnaire instead of the complete symptom list of mood disorders. It is typical for large-scale surveys using questionnaires with screening questions to save the assessment time. However, this creates tremendous difficulties in all types of statistical methods that require variable independence. It is a common trade-off between assessment time and information intactness. We recommend future studies with a narrower focus on screen time and mood problems using questionnaires without screening questions if feasible.

Sixth, the ABCD studies lacked in dimensional assessment for mood symptoms. Mood symptoms in the current study were assessed with the *K-SADS-5* (Kaufman et al. 2013) as dichotomous variables with inferior statistical properties than continuous variables. Considering the rising need for symptom-level analysis, we recommend that future researchers consider both the quality of disorder and symptom level data in the research design phase.

Seventh, the current study focused on preadolescents aged 9 to 10. As children experience rapid changes in physical, cognitive, and social development before young adulthood. The current findings may be specific to children in this age group. We recommend future research replicating similar quantitative models on children and adolescents of different ages to examine the generalizability of the current findings. Lastly, it is

crucial to investigate the robustness of the current results and other potential processes in underrepresented minorities.

Conclusions

In sum, the current study expands our understanding of the underexplored links between screen time and mood problems in preadolescents via a network approach. Our findings indicate that the content of screen time serves as a critical role in preadolescent mood problems. Additionally, we observed the moderating role of age-inappropriate screen time on the symptom relationships. Such that higher levels of engagement in age-inappropriate screen time were associated with tightened relationships in mood symptoms. Further, preadolescents engaged in age-inappropriate screen time may exhibit different symptom profiles of mood problems. These findings serve as foundations for future research that may facilitate early detection of preadolescents at high risks of mood problems.

Data Availability The current study was based on de-identified open datasets— the Adolescent Brain and Cognitive Development (ABCD) Study. The usage did not require IRB approval.

Compliance with Ethical Standards

Conflicts of Interest/Competing Interests   There is no conflict of interests to report for the present work.

Ethical Approval   All ABCD research sites relied on a central Institutional Review Board (cIRB) at the University of California, San Diego for ethical approval of the research protocol, with the exception of the site at Washington University in St. Louis utilizing their local IRB approval.

Informed Consent   Informed consent and assent of parents and children were obtained prior to the baseline assessment. All sites have complied with the ethical regulations during data collection, release, and analysis (Auchter et al. 2018). De-identified ABCD data can be accessed by NIH-recognized research institution with Federal-wide Assurance. The current use of the ABCD data for secondary analysis is exempt from IRB review, according to the IRB of Stony Brook University.

Code Availability   The current analyses were conducted based on open-source R packages, including *qgraph*, *mgm*, *bootnet*, and *NetworkComparisonTest*.

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