Association of Digital Media Use With Subsequent Symptoms of Attention-Deficit/Hyperactivity Disorder Among Adolescents

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IMPORTANCE Modern digital platforms are easily accessible and intensely stimulating; it is unknown whether frequent use of digital media may be associated with symptoms of attention-deficit/hyperactivity disorder (ADHD).

OBJECTIVE To determine whether the frequency of using digital media among 15- and 16-year-olds without significant ADHD symptoms is associated with subsequent occurrence of ADHD symptoms during a 24-month follow-up.

DESIGN, SETTING, AND PARTICIPANTS Longitudinal cohort of students in 10 Los Angeles County, California, high schools recruited through convenience sampling. Baseline and 6-, 12-, 18-, and 24-month follow-up surveys were administered from September 2014 (10th grade) to December 2016 (12th grade). Of 4100 eligible students, 3051 10th-graders (74%) were surveyed at the baseline assessment.

EXPOSURES Self-reported use of 14 different modern digital media activities at a high-frequency rate over the preceding week was defined as many times a day (yes/no) and was summed in a cumulative index (range, 0-14).

MAIN OUTCOMES AND MEASURES Self-rated frequency of 18 ADHD symptoms (never/rare, sometimes, often, very often) in the 6 months preceding the survey. The total numbers of 9 inattentive symptoms (range, 0-9) and 9 hyperactive-impulsive symptoms (range, 0-9) that students rated as experiencing often or very often were calculated. Students who had reported experiencing often or very often 6 or more symptoms in either category were classified as being ADHD symptom-positive.

RESULTS Among the 2587 adolescents (63% eligible students; 54.4% girls; mean [SD] age 15.5 years [0.5 years]) who did not have significant symptoms of ADHD at baseline, the median follow-up was 22.6 months (interquartile range [IQR], 21.8-23.0, months). The mean (SD) number of baseline digital media activities used at a high-frequency rate was 3.62 (3.30); 1398 students (54.1%) indicated high frequency of checking social media (95% CI, 52.1%-56.0%), which was the most common media activity. High-frequency engagement in each additional digital media activity at baseline was associated with a significantly higher odds of having symptoms of ADHD across follow-ups (OR, 1.11; 95% CI, 1.06-1.16). This association persisted after covariate adjustment (OR, 1.10; 95% CI, 1.05-1.15). The 495 students who reported no high-frequency media use at baseline had a 4.6% mean rate of having ADHD symptoms across follow-ups vs 9.5% among the 114 who reported 7 high-frequency activities (difference; 4.9%; 95% CI, 2.5%-7.3%) and vs 10.5% among the 51 students who reported 14 high-frequency activities (difference, 5.9%; 95% CI, 2.6%-9.2%).

CONCLUSIONS AND RELEVANCE Among adolescents followed up over 2 years, there was a statistically significant but modest association between higher frequency of digital media use and subsequent symptoms of ADHD. Further research is needed to determine whether this association is causal.

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Attention-deficit/hyperactivity disorder (ADHD)—a psychiatric condition involving persistent difficulty sustaining attention, hyperactivity, and impulsivity—was estimated to affect 7% of youth in a meta-analytic pooled estimate of studies published from 1981 to 2014,[1] and the rate may be increasing in some populations.[2] Because nongenetic environmental factors are associated with adolescent ADHD,[3] increasing exposure to environmental risk factors may contribute to increasing ADHD rates in that population.

A meta-analysis of studies conducted from 1987 to 2011 found that use of traditional forms of digital media (eg, television viewing and videogame console playing) was modestly associated with ADHD and related outcomes.[4] Digital media has since evolved. Modern digital platforms are diverse (eg, social networking, streaming movies or music, and texting), constantly available via mobile devices, and capable of providing rapid high-intensity stimulation. Whether the variety of modern digital media platforms currently available and the high frequency at which some teens use them increases risk of ADHD symptom occurrence is unknown.

This longitudinal cohort study of Los Angeles, County, California, high school students examined whether modern digital media-use frequency among 15- and 16-year-olds without significant ADHD symptoms was associated with subsequent ADHD symptom occurrence over a 24-month follow-up period. Secondarily, this study estimated the associations between high-frequency use of specific modern digital media platforms and ADHD symptom occurrence and between media use and ADHD symptom severity.

Methods

Participants and Procedures
Data were drawn from the Happiness & Health Study,[5] a longitudinal cohort survey of adolescents in Los Angeles. Among 40 local public high schools approached, 10 schools were selected based on their interest in participating, demographic composition, and proximity. Participating school characteristics in reference to Los Angeles County, California, public schools appear in eTable 1 in the Supplement. Participants and their parents provided active assent and consent prior to enrolling in the study when in ninth grade. Semiannual assessments were administered in classrooms. Students not present completed abbreviated surveys omitting key measures and are not included in this study. The University of Southern California institutional review board approved the study.

Variables for this study were measured in fall of 10th grade, referred to herein as the baseline survey. The sample included students who completed key measures and were classified as not having ADHD symptoms at baseline based on the Current Symptoms Self-Report Form score,[6] using definitions described below. Data analyzed include baseline (fall 2014, 10th grade) and 6-month (spring 2015, 10th grade), 12-month (fall 2015, 11th grade), 18-month (spring 2016, 11th grade), and 24-month (fall 2016, 12th grade) follow-ups.

Key Points

Question Is frequent use of modern digital media platforms, such as social media, associated with occurrence of ADHD symptoms during adolescence?

Findings In this longitudinal cohort survey study of adolescents aged 15 and 16 years at baseline and without symptoms of ADHD, there was a significant association between higher frequency of modern digital media use and subsequent symptoms of ADHD over a 24-month follow-up (odds ratio, 1.11 per additional digital media activity).

Meaning More frequent use of digital media may be associated with development of ADHD symptoms; further research is needed to assess whether this association is causal.

Measures

ADHD Symptoms
At each time point, students completed the Current Symptoms Self-Report Form[6] measure of the *Diagnostic and Statistical Manual of Mental Disorders–4th Edition* (*DSM-IV*)[7] ADHD symptom criteria, including 9 inattention symptoms (eg, difficulty organizing and completing tasks) and 9 hyperactivity-impulsivity symptoms (eg, trouble remaining still or with task persistence). Respondents rated the frequency that they experienced each symptom in the preceding 6 months: never or rare, 0; sometimes, 1; often, 2; or very often, 3. Consistent with recommendations[6] and *DSM-IV* criteria,[7] adolescents who reported experiencing 6 more symptoms in either inattention or hyperactivity-impulsivity categories were classified as having ADHD symptoms over the past 6 months; therefore, they were considered to be positive for ADHD symptoms—our study's primary binary outcome. Studies of self-assessment of ADHD symptoms compared with diagnoses made by clinical interviews have an estimated diagnostic sensitivity of 79% and a specificity of 60%.[8,9] The ADHD symptom severity score was a secondary outcome derived from the sum of the 0- to 3-symptom frequency ratings (range, 0-54), yielding adequate concordance with clinician-derived severity scores in previous work (Pearson rs ≥.72).[8]

Modern Digital Media Use
At baseline and at the 12- and 24-month follow-up surveys, students were asked to indicate how frequently they engaged in each of the 14 media activities in the past week (0, 1-2 times per week; 1-2 times per day; or many times per day). Each response was dichotomized into high-frequency (many times per day) vs other frequency levels (0, 1-2 times per week, 1-2 times per day) and summed in a cumulative media-use index that ranged from 0 to 14.

Covariates
To address possible confounding influences, baseline factors previously associated with digital media use or ADHD were included as covariates.[10-12] Self-report sociodemographic covariates were age (years), sex (male/female), and subsidized lunch eligibility, based in part on having a family income 185% or less than the US federal poverty guideline (yes/no). Because ADHD

prevalence may differ by race/ethnicity,[2] self-reported forced choice of 1 of 8 investigator-defined fixed race/ethnicity categories (American Indian/Alaska Native, Asian, black/African American, Hispanic/Latino, Native Hawaiian/Pacific Islander, white, multiethnic/multiracial, or other) was a covariate. American Indian/Alaska Native, Native Hawaiian/Pacific Islander, multiethnic/multiracial, or other responses constituted an *other* category.

Given behavioral and emotional problems in ADHD,[13] additional covariates included baseline self-reported delinquent behavior, measured with a sum of the frequency of 11 behaviors in the past 6 months (eg, stealing and skipping school; range, 1 [never] to 6 [≥10 times]),[14] the Center for Epidemiologic Studies Depression (CESD) scale[15] sum score of ratings (0, rarely or none of the time to 3, most or all of the time) of 20 depressive symptoms, substance use (current [past month] vs past [ever use, but no use in the past month] vs never use of cigarettes, alcohol, or cannabis), and family substance-use history (ie, siblings, parents, grandparents who reportedly smoked cigarettes or had an alcohol or drug-abuse problem, yes/no).

Statistical Analysis
Descriptive Analyses
Descriptive statistics of study variables, internal consistency estimates (Cronbach αs) for continuous variables, and stability estimates of associations across time points for the digital media frequency index (Pearson rs) and ADHD symptom status (φ coefficients) variables were calculated. Bivariate correlations between digital media index scores and ADHD symptom status (Point-biserial rs) for each time point were tested.

Main Analyses
Logistic random effect–repeated measures regression modeling was used to test the association of baseline digital media use, covariates, and time with likelihood of ADHD symptoms during the 6-, 12-, 18-, and 24-month follow-ups. The primary analysis used the cumulative digital media-use index (range, 0-14) regressor and the binary ADHD symptom status outcome. Secondary analyses tested associations of (1) high-frequency engagement in each media activity with ADHD symptom status in 14 separate repeated measures logistic regression models and (2) the cumulative digital media index with ADHD symptom severity score in repeated measures linear regression adjusted for baseline ADHD symptom severity among students at all levels of baseline ADHD symptoms.

We tested unadjusted and covariate-adjusted models. The digital media–use regressor estimate indicated the mean association with ADHD symptoms across the 4 follow-ups. Digital media use × time interaction terms were added in subsequent models to test whether the rate of change of ADHD symptom status or level across time was associated with baseline media use. Additional sensitivity analyses are summarized below and detailed in the eResults section of the Supplement.

Analyses were tested in Mplus[16] version 7 using 2-level random effects.[17] Time was nested within students, and school-level random effects were included. Missing data were man-

aged with full information maximum likelihood estimation. Odds ratios (ORs) or regression weights (bs) with 95% CIs were reported with statistical significance set at $P < .05$ (2-tailed). Benjamini-Hochberg multiple-testing corrections were applied to control the false-discovery rate at .05.[18]

Results

Study Sample
Participant accrual, sample size, and exclusions from the analytic sample are depicted in **Figure 1**. Among 4100 eligible ninth-grade students, 3874 (94.5%) assented, for whom 3396 (87.7%) provided consent and enrolled. Of the 3051 participants administered the baseline full-length survey, 2843 (93.2%) completed digital media and ADHD symptom measures, of whom, 2645 were below baseline ADHD symptom thresholds. After excluding 58 students (2.2%) who did not have follow-up data for 1 or more time points (eTable 2 in the Supplement depicts follow-up completion patterns), the primary analytic sample was 2587. Some groups of students excluded from the primary analysis were significantly older, had greater proportions of students eligible for subsidized lunch, and had different sex and race/ethnicity compositions (eTable 3 in the Supplement).

Descriptive Analyses
Of the 2587 students (63%) in the analytic sample, 54.4% were girls; 47.5%, Hispanic; 17.4%, Asian; 4.2%, black; 15.2%, white; and 15.7%, other. They were a mean (SD) age of 15.5 years (0.5 years) at baseline (**Table 1**).
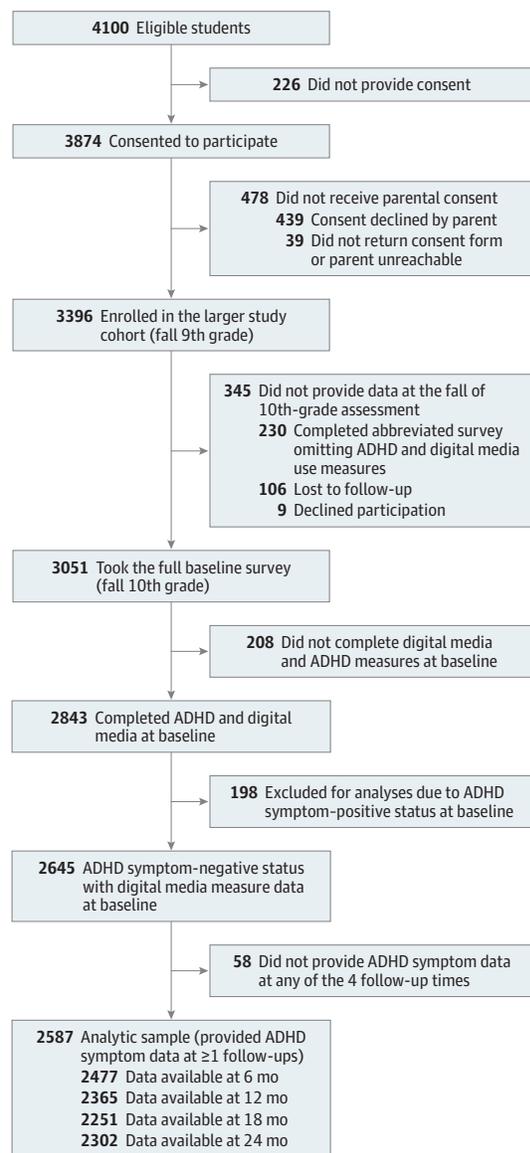
The distribution of high-frequency digital media activities had a mean (SD) of 3.62 (3.30) and was positively skewed (the number of students at each use-frequency level are reported along the horizontal axis of **Figure 2**E), with 2090 (80.9%) students reporting high-frequency use of at least 1 activity. Among study participants, 172 (6.9%) at 6 months; 113 (4.8%) at 12 months; 129 (5.7%) at 18 months, and 135 (5.9%) at 24 months had experienced ADHD symptoms in the 6-month intervals between surveys. Media-use index and ADHD symptom status internal consistency, stability, and bivariate association estimates were statistically significant at all time points (eTable 4 in the Supplement).

Primary Analysis
In the unadjusted logistic regression model, each additional baseline high-frequency digital media activity used was associated with significantly higher odds (OR, 1.11; 95% CI, 1.06-1.16) of positive (vs negative) ADHD symptom occurrence during the 6-months intervals between administration of the follow-up surveys (**Table 2**). Time and digital media use × time estimates indicate the ADHD symptom prevalence across follow-ups did not significantly change overall, and the rate of change in symptoms over time was not associated with media use.

The covariate-adjusted association between the index of digital media use and ADHD symptom status remained significant (OR, 1.10; 95% CI, 1.05-1.15). In this model, boys

Figure 1. Accrual of Adolescents in Study of Digital Media Use and ADHD

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┌─────────────────────────────────────────┐
│ 4100  Eligible students                   │
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        │
        │        ┌────────────────────────────────┐
        ├───────▶│ 226  Did not provide consent    │
        │        └────────────────────────────────┘
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│ 3874  Consented to participate            │
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        ├───────▶│ 478  Did not receive parental consent        │
        │        │ 439  Consent declined by parent              │
        │        │  39  Did not return consent form             │
        │        │      or parent unreachable                   │
        │        └────────────────────────────────────────────┘
        ▼
┌─────────────────────────────────────────┐
│ 3396  Enrolled in the larger study        │
│       cohort (fall 9th grade)             │
└─────────────────────────────────────────┘
        │
        │        ┌────────────────────────────────────────────┐
        ├───────▶│ 345  Did not provide data at the fall of     │
        │        │      10th-grade assessment                   │
        │        │ 230  Completed abbreviated survey            │
        │        │      omitting ADHD and digital media         │
        │        │      use measures                            │
        │        │ 106  Lost to follow-up                       │
        │        │   9  Declined participation                  │
        │        └────────────────────────────────────────────┘
        ▼
┌─────────────────────────────────────────┐
│ 3051  Took the full baseline survey       │
│       (fall 10th grade)                   │
└─────────────────────────────────────────┘
        │
        │        ┌────────────────────────────────────────────┐
        ├───────▶│ 208  Did not complete digital media          │
        │        │      and ADHD measures at baseline           │
        │        └────────────────────────────────────────────┘
        ▼
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│ 2843  Completed ADHD and digital          │
│       media at baseline                   │
└─────────────────────────────────────────┘
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        │        ┌────────────────────────────────────────────┐
        ├───────▶│ 198  Excluded for analyses due to ADHD       │
        │        │      symptom-positive status at baseline     │
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        ▼
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│ 2645  ADHD symptom-negative status        │
│       with digital media measure data     │
│       at baseline                         │
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        ├───────▶│  58  Did not provide ADHD symptom data       │
        │        │      at any of the 4 follow-up times         │
        │        └────────────────────────────────────────────┘
        ▼
┌─────────────────────────────────────────┐
│ 2587  Analytic sample (provided ADHD      │
│       symptom data at ≥1 follow-ups)      │
│ 2477  Data available at 6 mo              │
│ 2365  Data available at 12 mo             │
│ 2251  Data available at 18 mo             │
│ 2302  Data available at 24 mo             │
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Participants who did not provide data at the 4 follow-ups represent students who were not present during in-class data collections due to absence or being no longer enrolled at 1 of the study schools. See eTable 2 in the Supplement for the number of students completing 1 or multiple follow-up assessments. ADHD indicates attention-deficit/hyperactivity disorder.

(vs girls) and adolescents with more depressive symptoms and delinquent behaviors were at greater odds of experiencing ADHD symptoms during follow-up; other covariates were not associated with ADHD symptoms (Table 2).

The estimated mean symptom prevalence in the preceding 6 months across follow-ups by baseline of use of digital media derived from the unadjusted model are reported in eFigure 1 in the Supplement. Raw ADHD symptom prevalence across follow-ups, by baseline digital media-use index score are presented in Figure 2. The mean ADHD symptom prevalence was 4.6% for those who reported not using any digital

media activity at a high frequency at baseline compared with 9.5% for those who reported 7 high-frequency activities (difference, 4.9%; 95% CI, 2.5%-7.3%) and 10.5% for those who reported 14 high-frequency activities (difference, 5.9%; 95% CI, 2.6%-9.2%).

Secondary Analyses

The prevalence of high-frequency use of each media activity are presented in **Table 3** (left-hand columns). For example, 1398 adolescents (54.1%; 95% CI, 52.1%-56.0%) indicated checking social media sites at a high-frequency rate, the most common high-frequency activity reported. The next columns report the difference in mean ADHD symptom prevalence associated with high-frequency use (yes/no) for each activity. For 10 activities, high-frequency use was associated with an increased odds of ADHD symptoms across follow-ups after covariate adjustment.

Among the 2843 students above or below the baseline ADHD symptom cut point, 2777 (97.7%) provided ADHD symptom data for at least 1 follow-up, constituting the analytic sample for the secondary outcome. Repeated measures linear regression models adjusted for baseline ADHD symptom level found that each additional baseline high-frequency digital media activity used (range, 0-14) was associated with 0.11 (95% CI, 0.02-0.20) points higher on the ADHD symptom severity score (range, 0-54) across follow-ups (unadjusted b, 0.11; 95% CI, 0.02-0.20); the covariate-adjusted association was also statistically significant (b, 0.10; 95% CI, 0.01-0.19; all regression weights are reported in eTable 6 in the Supplement).

Sensitivity Analyses

Sensitivity analyses examining different approaches to handling missing data, adjusting for baseline subclinical ADHD symptoms, and bidirectional associations between media use and ADHD symptoms found significant associations between digital media use and subsequent ADHD symptoms in all cases (eFigure 2 and eResults in the Supplement). Psychometric analyses of the digital media-use measure offered preliminary support of the measure's validity and did not find that reliability differences between digital media use and ADHD measures explain their association across time (eResults and eTable 7 in the Supplement).

Discussion

In this study, high-frequency use of multiple forms of modern digital media was associated with increased odds of ADHD symptom occurrence over a 24-month period of mid-adolescence. Most previously reported relations of digital media use with ADHD symptoms were cross-sectional.[4] Prior longitudinal studies of this topic assessed exposure to traditional forms of media (television or videogame console playing), having collected data prior to the widespread availability of modern media platforms.[4] Modern and traditional digital media are not comparable due to marked differences in operating speed, level of stimulation, and

Table 1. Descriptive Statistics and Internal Consistency of Baseline Digital Media Use and Study Covariates in Participating Students

Baseline Variable	No. (%) of Students (n=2587)	Available No.[a]	Cronbach α[b]
Girls	1406 (54.3)	2587	
Age, mean (SD), y	15.5 (0.5)	2518	
Race/ethnicity		2528	
Hispanic	1201 (47.5)		
Asian	439 (17.4)		
Black	105 (4.2)		
White	385 (15.2)		
Other[c]	398 (15.7)		
Receiving subsidized lunch	1130 (48.2)	2343	
Substance use		2566	
Never	1369 (53.4)		
Past	607 (23.7)		
Current	590 (23.0)		
Family history of substance use	983 (39.9)	2467	
Delinquent behavior, mean (SD)[d]	14.3 (4.2)	2585	.73
CESD scale for depressive symptoms[e]			
Mean (SD)	14.3 (12.1)	2559	.82
Median (IQR)	15.8 (5.3-21.1)		
No. of digital media activities used at a high frequency rate[f]			
Mean (SD)	3.6 (3.3)	2587	.86
Median (IQR)	4.0 (1.0-5.0)		

Abbreviations: CESD, Center for Epidemiologic Studies Depression; IQR, interquartile range.

[a] The number of students with (nonmissing) data available for the respective variable and denominators for percentages reported for categorical variables.

[b] Chronbach α estimate of internal consistency reliability in study sample.

[c] See the Methods section for definition.

[d] Score ranges from 11 to 66, with higher scores indicating greater frequency of engaging in 11 different delinquent behaviors. Each behavior is rated from 1 (never) to 6 (10 or more times) for 11 behaviors.

[e] Scores range from 0 to 60, with higher scores indicating greater severity of past-week depressive symptoms. Each symptom rated 0 (rarely or none of the time; 0-1 day) to 3 (most or all of the time; 5-7 days) for 20 symptoms.

[f] Score ranges from 0 to 14, higher scores indicate greater digital media use. Total number of 14 different digital media activities engaged in at a high frequency rate (many times per day) over the preceding week.

potential for high-frequency exposure. Although some emerging research indicates that ADHD levels and use of certain forms of modern media may be concurrently associated,[19,20] the role of modern digital media use in ADHD risk largely remains unclear from the prior literature due to limitations in exposure assessment and the application of designs incapable of supporting temporal or causal inferences. The current study provides new longitudinal evidence on this topic using a 5-wave prospective design and comprehensive assessment across a wide continuum of digital media exposure, including numerous media platforms currently popular among youth.

In midadolescence, there is an inherent drive to develop social identity and cultivate interpersonal relationships.[21] Modern media platforms provide unprecedented opportunities for social connection. Teens can converse with dozens of peers simultaneously via group text messages. Social media permits instantaneous communication with thousands. Video chatting enables immediate face-to-face interactions. Midadolescence is also a period of high neural plasticity during which brain circuitry underlying attention and behavioral control mature rapidly and may be vulnerable to exposures that disrupt neurodevelopment.[22,23]
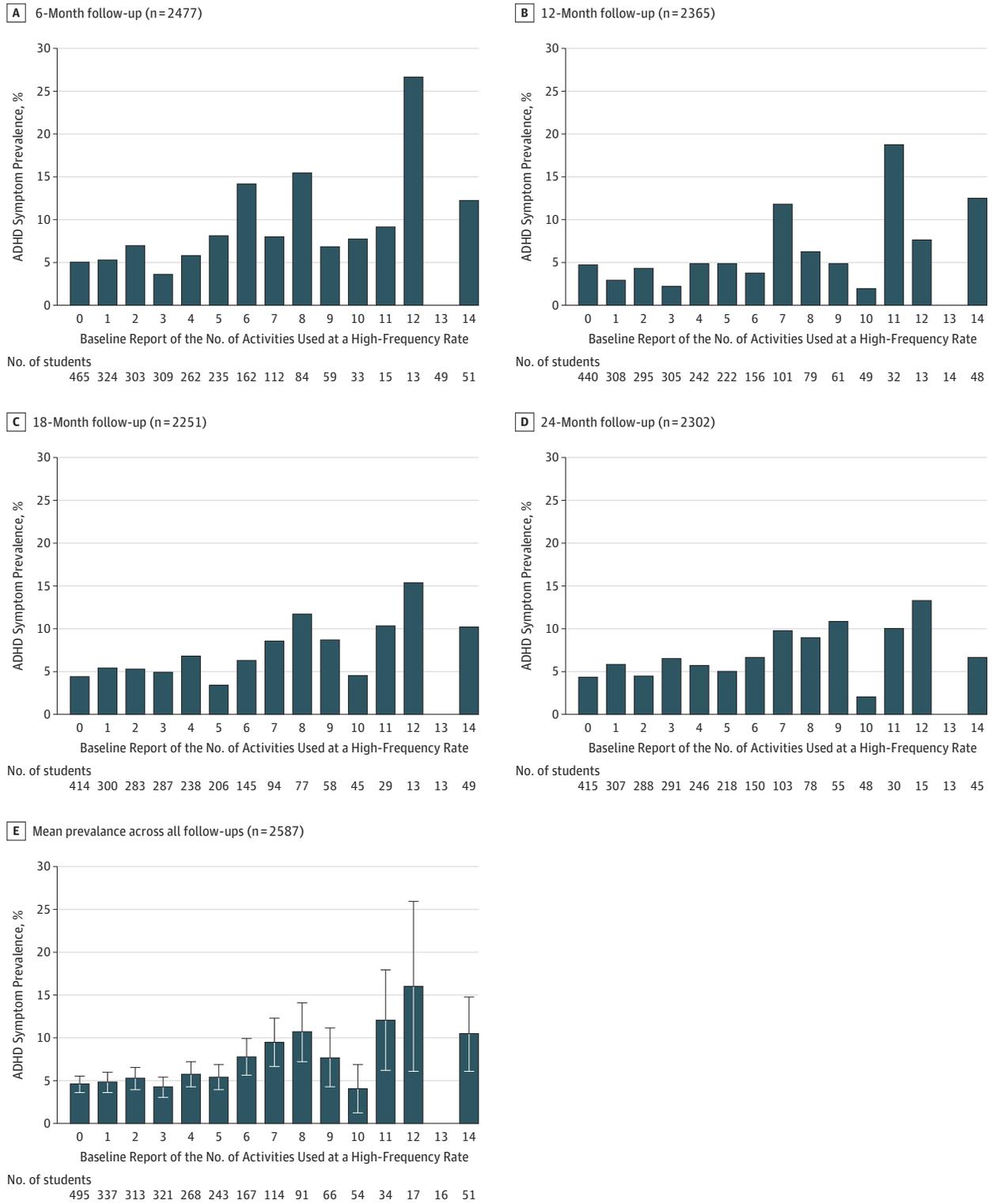
The course of ADHD is heterogeneous, and different symptom courses have been associated with distinct sources of risk.[24] Originally considered a childhood-onset persistent disorder, recent evidence demonstrates that adolescent- or adult-onset of ADHD symptoms that follow volatile trajectories across time are common and associated

with adverse health and social outcomes.[25,26] Volatile ADHD symptom patterns across follow-ups were also observed in this cohort. Whether high-frequency modern digital media use is associated with other ADHD symptom courses, including early childhood- or adult-onset presentations, warrants future inquiry.

The observed association between modern digital media use and subsequent ADHD symptoms may reflect noncausal mechanisms, including reverse causation. Attention-deficit/hyperactivity disorder is associated with sensation seeking,[27] which could promote pursuit of digital media to satisfy a drive for stimulation among youth who have ADHD symptoms. Although an association between ADHD level and subsequent modern digital media use was not found herein (eFigure 2 and eResults in the Supplement), an association between attention problems and subsequent videogame playing has been previously reported.[28]

Digital media use might have resulted from or be a proxy for subthreshold or undiagnosed ADHD, which was not detected at baseline and later manifested during follow-up. A sensitivity analysis addressing this explanation found that the primary association remained after adjusting for the subclinical ADHD symptom score—a covariate presumably associated with those with ADHD whose symptoms were undetected. The problem of overestimating or underestimating psychiatric disease due to misclassifying individuals with symptom levels close to diagnostic cut points can be reduced by using continuous symptom measures; digital media use was also associated with a continuous ADHD

Figure 2. Attention-Deficit/Hyperactivity Disorder (ADHD) Symptom Prevalence at Follow-ups, by Baseline Cumulative Digital Media Use Index Score of Participating High School Students

A 6-Month follow-up (n = 2477)

No. of students
465 324 303 309 262 235 162 112 84 59 33 15 13 49 51

B 12-Month follow-up (n = 2365)

No. of students
440 308 295 305 242 222 156 101 79 61 49 32 13 14 48

C 18-Month follow-up (n = 2251)

No. of students
414 300 283 287 238 206 145 94 77 58 45 29 13 13 49

D 24-Month follow-up (n = 2302)

No. of students
415 307 288 291 246 218 150 103 78 55 48 30 15 13 45

E Mean prevalance across all follow-ups (n = 2587)

No. of students
495 337 313 321 268 243 167 114 91 66 54 34 17 16 51

See the Methods section for determining ADHD symptoms. Score ranges from 0 to 14, higher scores indicate greater digital media use. Total number of 14 different digital media activities engaged in at a high-frequency rate (many times per day) over the preceding week. Panel E shows the ADHD mean symptom prevalence, across all 4 follow-up time points, weighted by the number of available observations, presented with error bars representing 95% CIs by the baseline level of digital media use.

symptom score in this study. Nevertheless, because this study did not assess diagnostic history, it remains possible that undetected baseline ADHD influenced the findings.

The association could also derive from shared risk factors. Common genetic or environmental influences may increase both ADHD symptoms and digital media access. Parents with ADHD, substance use problems, or other impulsive tendencies may apply lax parenting styles without restricting offspring digital media use.[29-31] Additionally, teens who admit frequent media use may be willing to report stigmatized conditions, such as ADHD, which may increase associations between these variables. Statistical adjustment for familial factors and other stigmatized behaviors sensitive to reporting biases, including family history of substance use, depressive symptoms, and delinquency, did not meaningfully affect the association. Still, the possibility that media use and ADHD symptoms are secondary to unknown (and unmeasured) common factors that operate across multiple time points cannot be ruled out.

Although alternative explanations remain possible, modern digital media use could play a role in the development of ADHD symptoms. The primary symptoms of ADHD are inattention (eg, distractibility, trouble with organization) and hyperactivity-impulsivity (eg, difficulty waiting, interrupting others, restlessness). Modern media devices immediately notify users when new text messages, social media postings, or videogame play invitations arrive. Exposure to such notifications may draw attention away from focal tasks. Frequent distractions could disrupt normative development of sustained attention and organization skills.[32] Additionally, modern media platforms provide instantaneous access to highly stimulating experiences and rapid feedback in response to user input. An array of information, music, television programs, movies, videogames, or digital social interactions are immediately accessible with modern media. Consequently, high-frequency modern digital media users may become accustomed to rapid feedback, which could disrupt development of impulse control and patience.

Even if modern digital media use is somehow implicated in risk of ADHD symptoms, any resulting public health or clinical implications are uncertain. The change in ADHD symptoms associated with each increment of media exposure in this study was modest and residual confounding could account for some of this association. Although the exposure-risk association was cumulative, appreciable differences in ADHD symptoms emerged primarily in comparisons of low and high ends of the media use continuum. Some adolescents in this study reported high-frequency use of numerous modern digital media platforms; however, they constituted a minor portion of the sample. Whether adolescent media exposure levels (and corresponding ADHD symptom risk) will change as digital technology further evolves remains to be seen.

Limitations

This study has several limitations. First, the ADHD symptom scale is capable only of identifying symptoms consistent with the disorder. The scale includes 18 items keyed

Table 2. Association of Baseline Cumulative Digital Media Use Index With Attention-Deficit/Hyperactivity Disorder Symptom Status Across Follow-ups[a]

Regression Variable	Past 6-Month ADHD Symptoms at Follow-ups, Odds Ratio (95% CI)[b]	P Value[b]
Unadjusted Model[c]		
Digital media activities used at a high-frequency rate, No.[d]	1.11 (1.06-1.16)	<.001
Time[e]	0.95 (0.87-1.04)	.29
No. of digital media activities used at a high-frequency rate × time[f]	0.98 (0.96-1.01)	.11
Adjusted Model[g]		
Digital media activities used at a high-frequency rate, No.[d]	1.10 (1.05-1.15)	<.001
Time[e]	0.95 (0.87-1.05)	.33
No. of digital media activities used at a high-frequency rate × time[f]	0.99 (0.97-1.01)	.30
Girls vs boys	0.41 (0.30-0.56)	<.001
Age (continuous variable)[h]	1.03 (0.79-1.32)	.85
Race/ethnicity		
Hispanic	1 [Reference]	
Asian	0.86 (0.48-1.51)	.59
Black	1.58 (0.72-3.49)	.26
White	0.99 (0.59-1.66)	.96
Other[i]	1.09 (0.64-1.84)	.76
Eligible for subsidized lunch (yes vs no)	0.73 (0.51-1.06)	.10
Substance use		
Never	1 [Reference]	
Past	1.29 (0.88-1.89)	.15
Current	1.40 (0.83-2.39)	.24
Family history of substance use (yes vs no)	1.12 (0.81-1.55)	.49
Delinquent behavior (continuous variable)[h,j]	1.36 (1.15-1.61)	<.001
CESD scale for depressive symptoms (continuous variable)[h,j]	1.90 (1.58-2.29)	<.001

Abbreviations: ADHD, attention-deficit/hyperactivity disorder; AIC, Akaike information criterion; BIC, Bayesian information criteria, CESD, Center for Epidemiologic Studies Depression.

[a] Includes 2587 participating students who did not surpass the ADHD self-report symptom scale threshold for the past 6-month ADHD symptoms (see the Methods section for determining ADHD symptoms).

[b] The estimate of the association of the respective regressor with ADHD symptom-positive (vs negative) status across follow-ups in repeated measures binary logistic regression models, including school random effects.

[c] Unadjusted model included the time-invariant baseline digital media use cumulative index variable and time variable as sole regressors (fit statistics: AIC, 3782.89; BIC, 3811.48).

[d] See the Methods section for frequency-use score determination.

[e] Time continuous variable (scored at 6 month, 0; 12 months, 1; 18 months, 2; and 24 months, 3).

[f] Interaction term added in subsequent models; ORs for other regressors are from models excluding the interaction term.

[g] The adjusted model included the time-invariant baseline digital media-use cumulative index variable, the time variable, and all baseline time-invariant covariates as simultaneous regressors (fit statistics: AIC, 73500.95, BIC, 73863.13).

[h] Rescaled (mean, 0; SD, 1) such that the odds ratios indicate the change in odds in the outcome associated with 1 SD higher on the regressor variable.

[i] See the Methods section for definition of the "Other" race category.

[j] See Table 1 footnote for score determination.

Table 3. Prevalence of High-Frequency Use of Each Digital Media Activity and Association With Attention-Deficit/Hyperactivity Disorder Symptom Status Across Follow-ups[a]

Digital Media Activity	Prevalence of High-Frequency Use, No. (%) of Students (n=2587)[b]	ADHD Symptom Prevalence Over Follow-ups Difference, % (95% CI)[c]	Association of High-Frequency Use With ADHD Symptoms at Follow-ups			
			Unadjusted[d]		Adjusted[e]	
			OR (95% CI)[f]	P Value[f]	OR (95% CI)[f]	P Value[f]
Checking social media sites	1398 (54.1)	1.2 (0.2 to 2.1)	1.36 (1.01 to 1.82)	.04[g]	1.53 (1.11 to 2.10)	.009[g]
Texting	1340 (52.1)	0.7 (−0.4 to 1.7)	1.17 (0.87 to 1.57)	.29	1.21 (0.89 to 1.65)	.22
Browsing or viewing images or videos	1105 (42.9)	1.9 (0.9 to 2.8)	1.58 (1.17 to 2.13)	.003[g]	1.45 (1.06 to 1.97)	.02[g]
Streaming or downloading music	992 (38.5)	2.1 (1.1 to 3.0)	1.60 (1.19 to 2.14)	.002[g]	1.50 (1.10 to 2.05)	.01[g]
Liking or commenting on others' statuses, wall posts, or pictures	734 (28.5)	2.0 (0.9 to 3.0)	1.69 (1.23 to 2.32)	.001[g]	1.67 (1.23 to 2.27)	.001[g]
Chatting online	680 (26.4)	1.1 (−0.2 to 2.3)	1.30 (0.94 to 1.79)	.10	1.34 (0.95 to 1.88)	.09
Streaming television or movies	649 (25.2)	2.1 (1.0 to 3.1)	1.58 (1.15 to 2.17)	.005[g]	1.45 (1.04 to 2.02)	.03[g]
Playing games by yourself on a console, computer, or smartphone	463 (18.0)	3.9 (2.6 to 5.1)	2.18 (1.54 to 3.09)	<.001[g]	1.97 (1.40 to 2.78)	<.001[g]
Reading online blogs, articles, news, forums, or books	456 (17.7)	2.4 (1.1 to 3.6)	1.65 (1.15 to 2.35)	.006[g]	1.54 (1.06 to 2.23)	.02[g]
Playing games with friends or family on a console, computer, or smartphone	394 (15.3)	2.3 (0.6 to 4.0)	1.57 (1.07 to 2.31)	.02[g]	1.40 (0.95 to 2.04)	.09
Sharing others' photographs, images, videos, status updates, blogs, articles, or news	330 (12.8)	2.4 (1.0 to 3.8)	1.74 (1.18 to 2.55)	.005[g]	1.58 (1.08 to 2.30)	.02[g]
Posting own photographs, images, videos, status updates, or blogs	316 (12.2)	2.0 (0.2 to 3.7)	1.52 (0.98 to 2.34)	.06	1.43 (0.92 to 2.23)	.12
Online shopping or browsing	261 (10.1)	2.5 (0.9 to 4.1)	1.81 (1.16 to 2.81)	.008[g]	1.71 (1.11 to 2.64)	.02[g]
Video chatting	226 (8.8)	4.8 (3.1 to 6.5)	2.36 (1.52 to 3.66)	<.001[g]	2.11 (1.39 to 3.22)	<.001[g]

Abbreviations: ADHD, attention-deficit/hyperactivity disorder; OR, odds ratio.

[a] Includes students who reported experiencing 5 or less inattentive or 5 or less hyperactive-impulsive symptoms often or very often at baseline.

[b] See the Methods section for frequency-use definitions.

[c] Mean ADHD symptom-positive prevalence across follow-ups among baseline high-frequency digital media users of respective activity subtracted by mean ADHD symptom-positive prevalence across follow-ups among students who did not report high-frequency use of respective activity, weighted by the number of available observations at each time point.

[d] Unadjusted models included a single time-invariant baseline high-frequency use binary variable for the respective media activity (yes/no) and the time variable as sole regressors.

[e] Adjusted models included a single time-invariant baseline high-frequency use binary variable for the respective media activity (yes/no), the time variable, and all baseline time-invariant covariates listed in Table 2 as simultaneous regressors.

[f] Estimate of association of high-frequency use of respective digital media activity at baseline (yes vs no) with ADHD symptom-positive (vs negative) status across follow-ups in repeated measures binary logistic regression models, including school random effects.

[g] Statistically significant after Benjamini-Hochberg corrections for multiple testing to control false-discovery rate at .05 (based on 2-tailed corrected P value).

exactly to the 18 *DSM-IV* ADHD symptoms, permitting classifications that correspond with *DSM-IV* diagnostic thresholds (≥6 inattention or hyperactivity-impulsivity symptoms). While moderate concordance between ADHD symptom status obtained by self-rating scales and ADHD diagnoses yielded from diagnostic interviews have been reported,[8,9] self-rating scales are insufficient for rendering ADHD diagnoses. Second, the media use measure's validity had not been previously established. Although this study found preliminary evidence of validity, evidence of the measure's concordance with objective digital device use indicators is needed to establish its validity. Third, the study focused on a targeted age range, used convenience sampling that resulted in 10 of 40 partnering schools from one region, and excluded students without data—a group that differed from the analytic sample on some demographic characteristics, which may affect generalizability. Fourth, the possibility that reverse causality or undetected baseline ADHD symptoms influenced the association cannot be ruled out.

Conclusions

Among adolescents followed up over 2 years, there was a statistically significant but modest association between higher frequency of digital media use and subsequent symptoms of ADHD. Further research is needed to determine whether this association is causal.

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