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Sleep insufficiency and bedtime irregularity in children with ADHD: A population-based analysis

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ABSTRACT

Background: Sleep is impaired in children with attention-deficit/hyperactivity disorder (ADHD). However, population-based examination of indicators of sleep insufficiency and bedtime irregularity is limited. This investigation examined associations between ADHD, weeknight sleep insufficiency, and bedtime irregularity in a nationally-representative child sample, and indicators of these sleep outcomes in ADHD.

Methods: Parents of children aged 3–17 years with ADHD (n = 7671) were surveyed through the 2020–2021 National Survey of Children's Health. Inverse probability of treatment weighting generated a weighted matched control sample (n = 51,572). Weighted generalized linear models were performed without and with age-stratification to examine associations between ADHD and sleep, adjusting for sociodemographics in the full sample, and between nineteen sociodemographic and clinical variables and sleep in ADHD.

Results: Having ADHD was associated with increased odds of sleep insufficiency and bedtime irregularity relative to controls, even after adjusting for sociodemographic variables. In ADHD, older age was associated with lower sleep insufficiency and greater bedtime irregularity. Black race, increased poverty, higher ADHD severity, depression, and increased screen time were associated with greater sleep insufficiency and bedtime irregularity. Adverse childhood experiences (ACEs) were associated with greater sleep insufficiency. Behavioral/conduct problems, female sex, and absence of both ADHD medication use and ASD diagnosis were associated with poorer bedtime irregularity. Age-stratified results are reported in text.

Conclusions: Children with ADHD face heightened risk for insufficient sleep and irregular bedtimes. Findings suggest intervention targets (e.g., Black race, poverty, depression, screen time) to improve both sleep insufficiency and bedtime irregularity. Results highlight ACEs and behavioral/conduct problems as targets to improve sleep insufficiency and bedtime regularity, respectively. Age-stratified findings are discussed.

1. Introduction

Sleep problems present in 25 %–50 % of children with attention-deficit/hyperactivity disorder (ADHD) [1] and lead to daytime sleepiness, attentional difficulties, hyperactivity, and school, social, and family impairment [2,3]. Common sleep problems include delayed bedtimes, delayed sleep onset, reduced sleep duration, and variability in sleep schedule [2–4].

Two important sleep domains are sleep sufficiency, referring to the alignment of sleep duration with age-based recommendations [5], and bedtime regularity [6]. Several studies have shown shorter sleep duration or insufficient sleep in children with ADHD relative to controls [7–9]. Fewer studies have examined bedtime regularity, but findings show greater bedtime variability in children with ADHD relative to controls [10]. However, we lack an understanding of factors which may differentially relate to sleep sufficiency and bedtime regularity.

Understanding these factors may aid identification of targeted interventions and provision of comprehensive care to curb sleep problems and associated impairment. Stimulant medication is one such factor; it is frequently linked to impaired sleep – most commonly sleep onset delay

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and shorter sleep duration [11], but is also suggested to reduce bedtime resistance [11,12]. Heightened ADHD severity, too, has been linked to increased sleep problems, including lack of sleep [13,14], though not all studies have observed this relationship [15].

Co-occurring psychiatric conditions are also associated with sleep problems in children with ADHD. Co-occurring anxiety and/or depression are associated with overall sleep problems and both longer and shorter sleep duration [7,14,16,17]. Co-occurring disruptive behavior disorders (e.g., conduct disorder, oppositional defiant disorder) have been associated with bedtime resistance and other dyssomnias (e.g., sleep onset difficulties) in select studies [7,16,18]. In addition, co-occurring autism spectrum disorder (ASD) has been associated with increased sleep problems in children with ADHD [19]. The co-occurrence of Tourette syndrome and ADHD can also enhance sleep problems [20]. Further, much attention has been given to the adverse impact of screen time on child sleep patterns – particularly shortened sleep duration and delayed sleep timing [21]. In children with ADHD, increased screen time in the hours before bed or in-bedroom screen access have been associated with greater sleep onset delay, shorter sleep duration, and greater overall sleep problems [17,22,23].

Several sociodemographic factors relevant to children with ADHD may influence sleep. Though ADHD displays male preponderance at a ratio of 3:1 [24], girls with ADHD have been reported to have more sleep problems than boys in select studies 25,26. Findings examining age-and-sleep associations in children with ADHD are mixed, as both younger age [9,27], and older age [28] have been associated with reduced sleep duration or insufficient sleep. Lower household income is associated with reduced sleep duration and quality [29]. Studies have shown mixed effects of minority status on sleep in children with ADHD, with non-white status associated with shorter sleep duration in one study [25], but no association found in another [7]. However, several studies show Black children followed by Hispanic children are at greater risk for shorter sleep duration and irregular bedtimes [30,31].

In addition, a number of medical and health-related factors relevant to children with ADHD are associated with sleep problems. For example, psychiatric medications commonly used to address co-occurring conditions (e.g., selective serotonin reuptake inhibitors) can adversely influence sleep in children [32]. In addition, asthma and sleep-disordered breathing difficulties [33], headache or migraine [34], health-related impairments [35], and overweight or obesity [36] are associated with increased sleep disturbance in children. Further, developmental factors (e.g., premature birth, adverse childhood experiences) implicated in ADHD are also linked to sleep disturbance, including short sleep duration [37,38].

The few available population-based studies examining sleep in children with ADHD have focused on circumscribed age ranges, limiting generalizability across childhood, and have seldom included controls [9]. In addition, bedtime irregularity has received limited empirical attention in children with ADHD. Therefore, this study evaluated the relationship between ADHD, sleep insufficiency, and bedtime irregularity in a population-based sample of 3–17-year-old children and key sociodemographic and clinical indicators in a subset with ADHD. Based on the consistency of associations between specific sociodemographic and clinical variables and bedtime and sleep outcomes reported across studies in child ADHD and the broader child literature, it was hypothesized that ADHD would be associated with sleep insufficiency and bedtime irregularity; ADHD medication, ADHD severity, co-occurring anxiety, depression, screen time, and Black race would be the most important indicators of sleep insufficiency; and ADHD severity, oppositional behavior, screen time, and Black race would be the most important indicators of bedtime irregularity.

2. Methods

2.1. Data source

Participants were drawn from the National Survey of Children's Health (NSCH) 2020 and 2021 combined database [39], which included 93,669 cases. The NSCH is a national survey conducted by the U.S. Census Bureau, evaluating children's health and well-being across physical and mental health, access to healthcare, and social determinants of health [40]. Households were randomly selected using a Census database of U.S. residential addresses across the 50 U S. states and District of Columbia [40]. Sampling was stratified within each state to maximize participation of households with children and organized to achieve balance across states with respect to high poverty neighborhoods. Participants completed an online or paper-based screening questionnaire assessing for the presence of children aged 0–17 years in the household. One child was randomly selected from each household to be the subject of the main questionnaire, which varied based on the child's age group. Children aged 0–5 years and children with special needs had a higher probability of being selected [40]. The institutional review board at the corresponding author's institution does not deem analysis of this deidentified data to meet the definitions of human subjects research.

2.2. Sample Selection and Participant Characteristics

Of the 8146 children with current ADHD, those with Down syndrome, current or lifetime cerebral palsy, and current or lifetime intellectual disability were excluded, yielding 7671 with current ADHD. In order to form an eligible group from which to select matched case controls, of the original 93,669 cases in the database, 41,336 were excluded for endorsement of Down syndrome, current or lifetime cerebral palsy, intellectual disability, speech and language disorder, ASD, ADHD, anxiety problems, depression, behavioral or conduct problems, Tourette syndrome, and receipt of mental health services in the past 12 months, yielding 52,333 cases. Inverse Probability of Treatment Weighting (IPTW), which entails calculating the probability or propensity of exposure versus non-exposure to a given risk factor (i.e., ADHD) based on specific characteristics [41], was performed using the WeightIt (Weighting for Covariate Balance in Observational Studies) package version 0.14.2 [42] in *R* version 4.3.2 [43] to form a matched case-control group from eligible control cases. We matched groups on age, sex, race and ethnicity, number of children in the household (assed via a rating of 1, 2, 3, and 4 or more), and current insurance status (insured [public health insurance only, private health insurance only, or both] versus uninsured). See Table 1 for descriptive statistics for covariates without and with adjusted weights.

As covariates used for propensity score weighting cannot have missing values, prior to IPTW, 101 more ADHD cases and 761 more control cases were excluded due to missing scores for the insurance status variable, yielding 7570 ADHD cases and 51,572 control cases. A pre-weighted balance check was then performed to evaluate the degree to which groups were balanced on covariates of interest. Chronological age, sex, and number of children in the household were not balanced between groups (see Supplementary Material 1 for balance measures). In IPTW, a propensity score was calculated by balancing the ADHD and control groups on age, sex, and number of children in the household by weighting each participant by the inverse probability of receiving their actual exposure. In addition, to account for the complex NSCH survey design and ensure results are generalizable to U.S. non-institutionalized children residing in housing units, sampling weights were incorporated into IPTW. Weighting incorporated strata (state of residence, and households with children), cluster (unique household identifier), and the child base weight. The function 'weightit' was used to specify complex sampling weights and the argument 's.weight' was used to specify that the 2020–2021 selected child weight be used to generate

Table 1
Descriptive statistics for covariates without and with adjusted weights.

	Unadjusted				Adjusted Weights			
	ADHD		Control		ADHD		Control	
	M	*SD*	*M*	*SD*	*M*	*SE*	*M*	*SE*
Age	12.04	3.59	9.41	4.59	11.63	0.09	9.60	0.04
Number of Children in the Household[a]	1.81	0.86	1.91	0.88	2.15	0.02	2.27	0.01
	n	%	*n*	%	*n*	%	*n*	%
Sex								
Female	2,461	32.5 %	25,949	50.3 %	26,494.44	46.59 %	28,377.14	47.99 %
Male	5,109	67.5 %	25,623	49.7 %	30,372.34	53.41 %	30,760.21	52.01 %
Race								
White, Non-Hispanic	5,475	72.3 %	33,503	65.0 %	36,779.82	64.68 %	38,972.30	65.90 %
Hispanic	840	11.1 %	6,956	13.5 %	7,704.88	13.55 %	7,796.89	13.18 %
Black, Non-Hispanic	508	6.7 %	3,477	6.7 %	4,112.80	7.23 %	3,986.55	6.74 %
Other/Multi-racial, Non-Hispanic	747	9.9 %	7,636	14.8 %	8,269.27	15.17 %	8,381.62	14.17 %
Insurance Status[b]								
Uninsured	270	3.6 %	2,643	5.1 %	3,018.15	5.31 %	2,912.31	4.92 %
Insured	7,300	96.4 %	48,929	94.9 %	53,848.63	94.69 %	56,225.04	95.08 %

Note. ADHD = attention-deficit/hyperactivity disorder; *M* = mean; *SD* = standard deviation; *SE* = standard error.
Data are drawn from the 2020–2021 National Survey of Children's Health (NSCH).
[a] Values represent responses from four categorical options (1 = 1 child; 2 = 2 children; 3 = 3 children; 4 = 4+ children).
[b] Insured refers to endorsement of public (government assistance) and/or private (privately purchased, including through ACA marketplace, through employer, or TRICARE) insurance.

nationally representative estimates [42]. Following propensity weighting, all covariates were balanced between groups (see Supplementary Material 1).

2.3. Measures

2.3.1. Sleep outcomes

2.3.1.1. Bedtime irregularity. Parents reported on their child's weeknight bedtime irregularity with, "How often does this child go to bed at about the same time on weeknights?" Parents rated this item using the following response options: 'always' (1), 'usually' (2), 'sometimes' (3), 'rarely' or 'never' (4).

2.3.1.2. Sleep insufficiency. Parents reported on their child's weeknight sleep duration with, "During the past week, how many hours of sleep did this child get [during an average day (count both nighttime sleep and naps) (0–5 years)/on most weeknights (6–17 years)]?" This item was rated using the following anchors for 0-5-year-old children: 'less than 7 h', '7 h', '8 h', '9 h', '10 h', '11 h', or '12 or more hours', and the following anchors for 6-17-year-old children: 'less than 6 h', '6 h', '7 h', '8 h', '9 h', '10 h', or '11 or more hours' and then recoded by the NSCH team according to age-based American Academy of Sleep Medicine guidelines [44] to obtain a binary variable indicating whether the child slept the recommended age-appropriate hours during an average day/on most weeknights. In the current study, sufficient sleep was coded 0 and insufficient sleep was coded 1.

2.3.2. Indicators

2.3.2.1. Sociodemographics. Participants reported on their child's race and ethnicity (Hispanic, white non-Hispanic, Black non-Hispanic, and Other/multi-racial non-Hispanic), age, sex, and annual household income before taxes (coded with reference to federal poverty level). For this study, this item was coded such that higher scores indicated a lower annual household income, using the following anchors: 400 % or greater (1), 200–399 % (2), 100–199 % (3), 0–99 % (4).

2.3.2.2. ADHD and Co-occurring psychiatric conditions. Parents reported on their child's lifetime and current psychiatric diagnoses (attention deficit disorder or ADHD, Tourette syndrome, anxiety problems, depression, behavioral or conduct problems, and autism or ASD, including Asperger's disorder and pervasive developmental disorder) with, "Has a doctor or other health care provider ever told you that this child has [condition]? If yes, does this child currently have the condition?" Only current psychiatric conditions were included as indicators for this study.

2.3.2.3. ADHD severity. Parents endorsing that their child had current ADHD rated the severity as 'mild' (1), 'moderate' (2), or 'severe' (3). We combined 'moderate' and 'severe' into a single category to improve distribution.

2.3.2.4. Psychiatric medication. Current ADHD Medication. For children identified as having ADHD, current ADHD medication use was assessed with, "Is this child currently taking medication for ADD or ADHD?"

Medication for Difficulties with Emotions, Concentration, or Behavior. Medication use for emotional, concentration, or behavioral challenges in the past year was assessed with, "During the past 12 months, has this child taken any medication because of difficulties with their emotions, concentrations, or behavior?"

2.3.2.5. Medical or health-related conditions. Headache or Migraine. Current headache or migraine was assessed using the prompts, "Has a doctor or other health care provider ever told you that this child has frequent or severe headaches, including migraines? Does this child currently have the condition?"

Breathing Difficulties. Parents rated child breathing difficulties in the past year with, "During the past 12 months, has this child had frequent or chronic difficulty with any of the following? Breathing or other respiratory problems (such as wheezing or shortness of breath)?"

Health Condition-related Interference. Parents rated the impact of their child's health conditions on their normal functioning in the past year with, "During the past 12 months, how often have this child's health conditions or problems affected their ability to do things other children their age do?" Response options included 'This child does not have any health conditions' (1) 'never' (2) 'sometimes' (3) 'usually' (4), and 'always' (5). 'This child does not have any health conditions' and 'never' were combined into one category prior to analysis, yielding anchors ranging from 1 to 4.

Overweight. Parents reported on their child's weight with, "Has a doctor or other healthcare provider ever told you that this child is

overweight?"

2.3.2.6. Developmental factors. Premature Birth. Premature birth status was queried with, "Was this child born more than 3 weeks before their due date?"

Adverse Childhood Experiences. ACEs, described in NSCH as events that may have happened during the child's life, were assessed via checklist. Experiences queried included parental divorce or separation, parental death, parental incarceration (i.e., jail or prison), exposure to parental domestic violence, victim of violence or exposure to neighborhood violence, living with one or more individuals with mental illness, suicidality, or severe depression, living with one or more individuals with alcohol or drug problems, judgment or unfair treatment based on race or ethnicity, and unfair judgment or treatment based on sexual orientation or gender identity. An additional ACE item pertained to economic hardship and was represented through a response of 'somewhat often' or 'very often' to the question, "Since this child was born, how often has it been very hard to cover the basics, like food or housing, on your family's income?" A composite measure of number of ACEs was generated by summing the number of ACEs endorsed from 0 to 10.

2.3.2.7. Screen time. Average daily screen time was assessed with, "On most weekdays, about how much time does this child usually spend in front of a TV, computer, cellphone, or other electronic device watching programs, playing games, accessing the internet, or using social media?" The response options for this question were: 'less than 1 h' (1), '1 h' (2), '2 h' (3), '3 h' (4), and '4 or more hours' (5). Note, 'less than 1 h' and '1 h' were combined into a single category prior to analysis to improve distribution.

2.4. Data analysis

Weighted generalized linear model (GLM) analyses were performed using the 'Survey' package in *R* [43,45]. A weighted binomial generalized linear model (GLM) was performed to evaluate the degree to which ADHD versus control group status was associated with insufficient sleep (binary outcome) and a weighted conventional GLM was performed to examine the extent to which ADHD versus control group status was associated with bedtime irregularity (treated as a continuous variable). Both GLM analyses were performed without and with statistical control for covariates (chronological age, sex, race and ethnicity, number of children in the home, and insurance status). The nineteen demographic and clinical variables (as described in *Measures*) were entered as indicators. Sleep sufficiency and bedtime regularity were entered as dependent variables. A weighted binomial GLM was performed to evaluate the degree to which indicators were associated with sleep insufficiency. A weighted conventional GLM was performed to evaluate the degree to which these indicators were associated with bedtime irregularity.

3. Results

3.1. Weighted binomial GLM for ADHD predicting sleep insufficiency and weighted conventional GLM for ADHD predicting bedtime irregularity in total sample

In the unadjusted model (see Table 2), having current ADHD was associated with significantly higher odds (OR = 0.62) of insufficient sleep relative to healthy controls (OR = 0.38. $t = 16.27, p < 0.001$). This finding remained significant ($t = 15.91$, $p < 0.001$) after adjusting for age, sex, race, number of children in the home, and insurance status. Current ADHD was associated with 0.96 adjusted odds of insufficient sleep, while healthy control status was associated with 0.58 adjusted odds. In the unadjusted model (see Table 3), having current ADHD was

Table 2
Weighted binomial generalized linear model estimates for ADHD versus control group status as an indicator of insufficient sleep without and with adjustment for covariates.

	OR Est.	CI (2.5 %)	CI (97.5 %)	*t*	*p*
Without Adjustment for Covariates					
Intercept	0.38	0.38	0.39	−96.39	<0.001
ADHD versus Control	1.63	1.54	1.73	16.27	<0.001
With Adjustment for Covariates					
Intercept	0.58	0.48	0.71	−5.50	<0.001
ADHD versus Control	1.65	1.55	1.76	15.91	<0.001
Age	0.99	0.98	0.99	−4.02	<0.001
Sex (Reference = Female)					
Male	0.97	0.91	1.03	−1.10	0.272
Race (Reference = White, Non-Hispanic)					
Hispanic	1.29	1.17	1.42	5.17	<0.001
Black, Non-Hispanic	2.68	2.40	3.00	17.23	<0.001
Other/Multi-racial, Non-Hispanic	1.24	1.12	1.37	4.19	<0.001
Number of Children in the Household[a]	1.00	0.97	1.04	0.21	0.832
Insurance Status (Reference = Uninsured)[b]					
Insured	0.65	0.56	0.76	−5.46	<0.001

Note. OR Est. = odds ratio estimate; CI = confidence interval; ADHD = attention-deficit/hyperactivity disorder.
Data are drawn from the 2020–2021 National Survey of Children's Health (NSCH).
[a] Values represent responses from four categorical options (1 = 1 child; 2 = 2 children; 3 = 3 children; 4 = 4+ children).
[b] Insured refers to endorsement of public (government assistance) and/or private (privately purchased, including through ACA marketplace, through employer, or TRICARE) insurance.

Table 3
Weighted conventional generalized linear model estimates for ADHD versus control group status as an indicator of bedtime irregularity without and with adjustment for covariates.

	B	CI (2.5 %)	CI (97.5 %)	*t*	*p*
Without Adjustment for Covariates					
Intercept	1.86	1.85	1.86	610.03	<0.001
ADHD versus Control	0.17	0.15	0.19	13.99	<0.001
With Adjustment for Covariates					
Intercept	1.67	1.58	1.76	38.14	<0.001
ADHD versus Control	0.14	0.12	0.17	11.65	<0.001
Age	0.03	0.03	0.04	21.73	<0.001
Sex (Reference = Female)					
Male	−0.04	−0.06	−0.02	−3.42	0.001
Race (Reference = White, Non-Hispanic)					
Hispanic	0.06	0.02	0.10	3.07	0.002
Black, Non-Hispanic	0.29	0.23	0.35	9.30	<0.001
Other/Multi-racial, Non-Hispanic	0.06	0.02	0.10	3.22	0.001
Number of Children in the Household[a]	−0.02	−0.04	−0.01	−3.21	0.001
Insurance Status (Reference = Uninsured)[b]					
Insured	−0.11	−0.18	−0.03	−2.85	0.004

Note. B = unstandardized beta coefficient; CI = confidence interval.
ADHD = attention-deficit/hyperactivity disorder.
Data are drawn from the 2020–2021 National Survey of Children's Health (NSCH).
[a] Values represent responses from four categorical options (1 = 1 child; 2 = 2 children; 3 = 3 children; 4 = 4+ children).
[b] Youth were categorized as uninsured if endorsed using public (government assistance) and/or private (privately purchased, including through ACA marketplace, through employer, or TRICARE) insurance.

Table 4
Weighted binomial generalized linear model estimates for indicators of insufficient sleep in children with ADHD.

	OR Est.	CI (2.5 %)	CI (97.5 %)	*t*	*p*
Intercept	0.27	0.19	0.39	−6.94	<0.001
Age	0.95	0.93	0.97	−5.00	<0.001
Sex (Reference = Female)					
Male	0.95	0.84	1.07	−0.88	0.380
Race (Reference = White, Non-Hispanic)					
Hispanic	0.98	0.81	1.18	−0.19	0.851
Black, Non-Hispanic	2.08	1.65	2.63	6.14	<0.001
Other/Multi-racial, Non-Hispanic	1.18	0.97	1.43	1.64	0.101
Federal Poverty Level[a]	1.28	1.21	1.36	8.37	<0.001
Current Co-occurring Psychiatric Conditions (Reference = No Disorder)					
Tourette Syndrome	0.55	0.30	1.02	−1.89	0.059
Anxiety Problems	0.88	0.76	1.02	−1.70	0.090
Depression	1.25	1.05	1.49	2.49	0.013
Behavioral or Conduct Problems	0.92	0.80	1.05	−1.25	0.211
Autism or Autism Spectrum Disorder	1.11	0.92	1.34	1.06	0.287
ADHD Severity – Current	1.19	1.04	1.36	2.54	0.011
Medication (Reference = No Medication)					
Medication for ADHD – Current	1.14	0.96	1.35	1.46	0.146
Medication for Emotional Problems – Past 12 Months[b]	0.88	0.74	1.05	−1.41	0.159
Headache or Migraine – Current	1.03	0.82	1.28	0.24	0.814
Breathing Difficulties – Past 12 Months	1.06	0.86	1.30	0.55	0.580
Health Condition-related Interference – Past 12 Months (Reference = No Health-related Condition/Never) Sometimes, Usually, or Always[c]	0.92	0.84	1.01	−1.79	0.074
Overweight – Lifetime	1.17	0.97	1.40	1.64	0.101
Premature Birth	1.06	0.90	1.25	0.70	0.481
Number of Adverse Childhood Experiences[d]	1.04	1.00	1.07	1.98	0.048
Screen Time – Average Daily[e]	1.23	1.16	1.30	6.97	<0.001

Note. OR Est. = odds ratio estimate; CI = confidence interval; ADHD = attention-deficit hyperactivity disorder.
Data are drawn from the 2020–2021 National Survey of Children's Health.
[a] Federal poverty level was coded with the following four categorical options (1 = 400 % or greater, 2 = 200–399 %, 3 = 100–199 %, 4 = 0–99 %). Higher values indicate lower annual family income.
[b] Only parents who endorsed that their child had emotional problems in the past 12 months were asked to report on medication for emotional problems.
[c] Children were categorized as experiencing health-condition-related interference if they endorsed impairment sometimes, usually, or always. For the reference group, endorsement of no health-related condition or never were combined into a single category.
[d] Adverse childhood experiences are represented on a 0–10 scale, with 0 representing no adverse childhood experiences and 10 representing 10 adverse childhood experiences.
[e] Average daily screen time features the following four categorical response options (1 = 1 h or less than 1 h; 2 = 2 h; 3 = 3 h; 4 = 4 or more hours).

associated with significantly greater bedtime irregularity ($t = 13.99$, $p < 0.001$). Healthy controls had bedtime irregularity of 1.86 points and children with current ADHD had bedtime irregularity that was 0.17 units higher. Following adjustment for covariates (age, sex, race, number of children in the home, and insurance status), current ADHD status remained associated with significantly greater bedtime irregularity ($t = 11.65$, $p < 0.001$). Bedtime irregularity was 1.67 points for healthy controls and 0.14 points higher for children with current ADHD.

Table 5
Weighted conventional generalized linear model estimates for indicators of bedtime irregularity in children with ADHD.

	B	CI (2.5 %)	CI (97.5 %)	*t*	*p*
Intercept	1.10	0.95	1.24	14.69	<0.001
Age	0.03	0.02	0.04	6.43	<0.001
Sex (Reference = Female)					
Male	−0.06	−0.11	−0.02	−2.61	0.009
Race (Reference = Hispanic)					
White, non-Hispanic	−0.02	−0.10	0.05	−0.63	0.526
Black, non-Hispanic	0.29	0.18	0.40	5.07	<0.001
Other/Multi-racial, non-Hispanic	0.04	−0.03	0.12	1.15	0.250
Federal Poverty Level[a]	0.04	0.01	0.06	3.05	0.002
Current Co-occurring Psychiatric Conditions (Reference = No Disorder)					
Tourette Syndrome	0.00	−0.16	0.17	0.02	0.981
Anxiety Problems	−0.04	−0.09	0.01	−1.52	0.128
Depression	0.19	0.12	0.26	5.42	<0.001
Behavioral or Conduct Problems	0.07	0.02	0.12	2.93	0.003
Autism or Autism Spectrum Disorder	−0.09	−0.17	−0.02	−2.42	0.015
ADHD Severity – Current	0.06	0.01	0.11	2.31	0.021
Medication (Reference = No Medication)					
Medication for ADHD – Current	−0.16	−0.23	−0.09	−4.62	<0.001
Medication for Emotional Problems – Past 12 Months[b]	0.01	−0.06	0.09	0.40	0.689
Headache or Migraine – Current	0.08	−0.01	0.17	1.69	0.090
Breathing Difficulties – Past 12 Months	0.03	−0.05	0.11	0.68	0.500
Health Condition-related Interference – Past 12 Months (Reference = No Health-related Condition/Never) Sometimes, Usually, or Always[c]	0.03	−0.01	0.07	1.68	0.094
Overweight – Lifetime	0.04	−0.04	0.11	0.94	0.347
Premature Birth	−0.03	−0.09	0.04	−0.82	0.411
Number of Adverse Childhood Experiences[d]	0.01	−0.00	0.03	1.82	0.068
Screen Time – Average Daily[e]	0.16	0.14	0.19	14.11	<0.001

Note. B = unstandardized beta coefficient; CI = confidence interval; ADHD = attention-deficit hyperactivity disorder.
Data are drawn from the 2020–2021 National Survey of Children's Health.
[a] Federal poverty level was coded with the following four categorical options (1 = 400 % or greater, 2 = 200–399 %, 3 = 100–199 %, 4 = 0–99 %). Higher values indicate lower annual family income.
[b] Only parents who endorsed that their child had emotional problems in the past 12 months were asked to report on medication for emotional problems.
[c] Children were categorized as experiencing health-condition-related interference if they endorsed impairment sometimes, usually, or always. For the reference group, endorsement of no health-related condition or never were combined into a single category.
[d] Adverse childhood experiences are represented on a 0–10 scale, with 0 representing no adverse childhood experiences and 10 representing 10 adverse childhood experiences.
[e] Average daily screen time was coded using the following four categorical options (1 = 1 h or less than 1 h; 2 = 2 h; 3 = 3 h; 4 = 4 or more hours).

3.2. *Weighted binomial generalized linear model for indicators of insufficient sleep in children with ADHD (Table 4)*

Chronological age was a significant, negative indicator of sleep insufficiency, such that younger chronological age was associated with higher odds of sleep insufficiency ($t = -5.00$, $p < 0.001$). Black race ($t = 6.14$, $p < 0.001$), household income below poverty level ($t = 8.37$, $p < 0.001$), higher ADHD severity ($t = 2.54$, $p = 0.011$), current depression ($t = 2.49$, $p = 0.013$), increased screen time ($t = 6.97$, $p < 0.001$), and higher number of adverse childhood experiences ($t = 1.98$, $p =$

0.048) were associated with higher odds of sleep insufficiency.

3.3. Weighted conventional generalized linear model for indicators of bedtime regularity in children with ADHD (Table 5)

Older chronological age ($t = 6.43, p < 0.001$), female sex ($t = -2.61$, $p = 0.009$), Black race ($t = 5.07, p < 0.001$), annual household income below poverty level ($t = 3.05$, $p = 0.002$), current ADHD severity ($t = 2.31$, $p = 0.021$), current depression ($t = 5.42$, $p < 0.001$), current behavioral or conduct problems ($t = 2.93, p = 0.003$), and screen time ($t = 14.11, p < 0.001$) were associated with greater bedtime irregularity. In contrast, current ADHD medication use ($t = -4.62, p < 0.001$), and current autism or ASD ($t = -2.42, p = 0.015$) were associated with less bedtime irregularity.

3.4. Weighted binomial generalized linear model for ADHD predicting sleep insufficiency and weighted conventional generalized linear model for ADHD predicting bedtime irregularity in children stratified by age group (3–11 years and younger and 12–17 years and older)

In order to explore the role of adolescent development on outcomes, we subsequently divided the sample into children aged 3–11 years (3181 with ADHD; 32,361 healthy controls) and 12–17 years (4389 with ADHD; 18,941 healthy controls). Then age-stratified ADHD and control groups were separately balanced on sociodemographics using IPTW as described in section 2.2. Sample Selection and Participant Characteristics above and Supplementary Material 1. Findings are detailed below.

Among children in both age groups, the unadjusted model (see Tables S1 and S2 in Supplementary Material 2) showed current ADHD (3–11 years: OR = 0.72; 12–17 years: OR = 0.52) was associated with higher odds of insufficient sleep relative to healthy controls (3–11 years: OR = 0.41, $t = 11.50, p < 0.001$; 12–17 years: OR = 0.36, $t = 9.94, p < 0.001$). After adjusting for covariates, current ADHD (3–11 years: OR = 0.84; 12–17 years: OR = 0.68) remained associated with higher odds of insufficient sleep relative to healthy controls (3–11 years: OR = 0.49, $t = 10.05, p < 0.001$; 12–17 years: OR = 0.46, $t = 10.16, p < 0.001$) after adjusting for covariates. The unadjusted model (see Tables S3 and S4) showed current ADHD was associated with greater bedtime irregularity (3–11 years: $t = 5.98, p < 0.001$; 12–17 years: $t = 16.44, p < 0.001$). Following adjustment for covariates, current ADHD remained significantly associated with greater bedtime irregularity (3–11 years: $t = 5.10$, $p < 0.001$; 12–17 years: $t = 16.65, p < 0.001$).

3.5. Weighted binomial generalized linear model for indicators of insufficient sleep in children with ADHD stratified by age group (3–11 years and 12–17 years)

In children with ADHD aged 3–11 years, Black race ($t = 3.93, p < 0.001$), annual household income below poverty level ($t = 7.47, p < 0.001$), current ADHD severity ($t = 2.75$, $p = 0.006$), and increased screen time ($t = 4.80, p < 0.001$) were associated with higher odds of insufficient sleep (see Table S5). Current anxiety was associated with significantly lower odds of sleep insufficiency ($t = -2.18$, $p = 0.029$). Among children with ADHD aged 12–17 years, Black race ($t = 4.51, p < 0.001$) and screen time ($t = 3.25, p = 0.001$) were associated with higher odds of sleep insufficiency (see Table S6).

3.6. Weighted conventional generalized linear model for indicators of bedtime regularity in children with ADHD stratified by age group (3–11 years and 12–17 years)

In children with ADHD aged 3–11 years, female sex ($t = -2.30$, $p = 0.021$), Black race ($t = 4.01, p < 0.001$), annual household income below poverty level ($t = 1.18, p = 0.238$), and screen time ($t = 7.46, p < 0.001$) were associated with greater bedtime irregularity (see Table S7). In children with ADHD aged 12–17 years, older chronological age ($t = 7.91, p < 0.001$), Black race ($t = 2.58$, $p = 0.010$), annual household income below poverty level ($t = 3.04, p = 0.002$), current ADHD severity ($t = 3.61, p < 0.001$), headache or migraine ($t = 3.15$, $p = 0.002$), current depression ($t = 5.82, p < 0.001$), current behavior or conduct problems ($t = 3.65, p < 0.001$), and screen time ($t = 11.74, p < 0.001$) were associated with greater bedtime irregularity (see Table S8). Current ADHD medication use ($t = -3.35, p < 0.001$), current autism or ASD ($t = -6.28, p < 0.001$), and premature birth ($t = -3.29, p = 0.001$) were associated with less bedtime irregularity.

4. Discussion

This study examined whether ADHD was associated with sleep insufficiency and bedtime irregularity in a population-based sample of U.S. children, as well as sociodemographic and clinical indicators. Children with ADHD were more likely to have increased sleep insufficiency and bedtime irregularity relative to controls, and age-stratified findings were consistent. Findings align with hypotheses and studies reporting increased sleep problems in children with ADHD [8,46].

4.1. ADHD-related indicators

The association between ADHD severity and both sleep insufficiency and bedtime irregularity suggests the need for management of ADHD severity to improve sleep. Stimulant medication is a first-line intervention for ADHD [47], but associated with adverse sleep effects [11]. Interestingly, here, ADHD medication use was linked to less bedtime irregularity across full and age-stratified samples, and not related to sleep insufficiency. However, research indicates the association between stimulant use and sleep problems is attenuated with longer duration of use, and also suggests the potential for stimulants to produce positive effects on sleep through reduced bedtime resistance [11,12]. Further, ADHD medication type, not specified, may have influenced outcomes. Alpha-2-adrenergic agonists (e.g., clonidine), frequently prescribed as sleep aids in children and efficacious for treating ADHD, show promise in improving sleep in children with ADHD [48,49]. In addition, behavior therapy (e.g., behavioral parent training) alone or in combination with medication is efficacious for ADHD in children [47]. In one study, combined behavior therapy with methylphenidate for ADHD was associated with reductions in parent-reported sleep problems relative to community care, whereas behavior therapy alone and methylphenidate alone were not [50], suggesting the benefit of blended treatments which address behavior and physiology to manage both ADHD symptoms and sleep problems.

4.2. Screen time

The statistical significance of screen time as an indicator of both sleep outcomes across full and age-stratified samples was not surprising, based on the numerous studies demonstrating its associations with sleep disturbance [21]. However, the directionality of this association and implicated mechanisms are unclear. Engaging in screen time may displace sleep, shifting bedtimes later; the media content itself may be cognitively and/or physiologically stimulating competing with sleep initiation; and/or text messages, email, and other device alerts may directly disrupt sleep ([51] [52]). In addition, light-emitting devices have been associated with small increases in the minutes it takes to fall asleep in adults, though their impact on sleep in children is unclear [52, 53]. However, it is important to note that the association between screen time and sleep problems, particularly for adolescents, may be partially accounted for by use of screens to pass the time while waiting to fall asleep in the face of sleep difficulties or to regulate or distract from aversive emotions (e.g., anxiety) commonly linked to sleep challenges [54–56]. Longitudinal studies are needed to elucidate the temporal association between screen time and sleep patterns. Nevertheless, findings suggest the importance of determining the function of screen use for

youth and addressing screen use as part of multi-element sleep interventions that address numerous aspects of sleep disturbance (e.g., sleep hygiene, nighttime anxiety, stimulus control, etc.).

4.3. Sociodemographic indicators

The finding that Black race was a significant indicator of both sleep outcomes across full and age-stratified samples aligns with the extant research showing shorter relative sleep duration and irregular bedtimes in Black children [30,31]. Research is needed to understand the experience of Black children with ADHD surrounding sleep. Sleep problems (e.g., difficulty falling asleep), exhaustion, and needing naps were identified as themes among racially and ethnically minoritized youth reporting on their experience with ADHD [57]. Increased daytime napping may perpetuate short sleep duration and also serve to restore lost sleep duration [58]. In addition, parenting practices (e.g., reduced bedtime routine consistency and independent child sleeping in Black families) mediate racial discrepancies in sleep in young children [59].

The association between reduced household income and both sleep outcomes may relate to household disorganization and sleep environment (e.g., room temperature, comfort of bed, light and noise inside room) [60–62]. In addition, bed sharing, present at higher rates in families of lower SES, is associated with shorter sleep duration [63]. This suggests the need for interventions geared toward socioeconomic context. An intervention entailing provision of a child's bed as well as sleep education to mothers from families of lower SES was associated with improved sleep and internalizing and externalizing symptoms [64].

The association between female sex and bedtime irregularity appears driven by the adolescent sample, and is consistent with findings showing adolescent females display greater sleep problems than males [65]. The degree to which sex hormones play a role in sex discrepancies in sleep in children with ADHD is worth future exploration [66]. The relationship found between older chronological age and greater bedtime irregularity was driven by the adolescent group and may be attributed to fewer parental rules and oversight surrounding bedtime with advancing age [67].

4.4. Co-occurring psychiatric indicators

The finding that depression, but not anxiety, was a significant indicator of both sleep insufficiency and bedtime irregularity in the full sample, and anxiety was associated with less insufficient sleep in children aged 3–11 years is surprising, as both anxiety and depression are associated with sleep disturbance in children with ADHD [7,14,16,17]. Results suggest the utility of prevention or treatment of depression in children with ADHD to improve sleep. The Behaviorally Enhancing Adolescents Mood Program, and the Integrated Parenting Intervention for ADHD show promise for depression prevention in children with ADHD 68,69, though their impact on sleep has yet to be examined. Children in the 3-11-year range with ADHD and co-occurring anxiety may require more structure and parental oversight surrounding the sleep process, and older children in this age range may worry about obtaining sufficient sleep, contributing to the higher likelihood of obtaining the age-recommended number of hours of sleep.

As anticipated, behavioral or conduct problems were associated with bedtime regularity but not sleep sufficiency. Our finding is consistent with the few studies demonstrating oppositional behavior is associated with increased bedtime resistance in children with ADHD [16,18]. Behavioral parent training targeting sleep may have utility for disruptive behavior or conduct problems, as it is efficacious for improving bedtime resistance and overall sleep problems in school-aged children with ADHD [70]. The association of ASD with less bedtime irregularity was unexpected, and contributes to the mixed findings in the literature ([19]; [71]). Although speculative, our current finding might be partially explained by greater parental involvement in bedtime for children with ADHD with co-occurring autism, which could lead to less variable bedtime but have less impact on sleep sufficiency.

4.5. Developmental and medical indicators

In the present investigation, ACEs were an additional indicator of greater sleep insufficiency, consistent with prior studies [37,72], but not bedtime irregularity in the full sample. This is supported by studies showing associations between ACEs and insufficient sleep [37,72]. Purported underlying mechanisms for this association include disruptions to the circadian system adversely influencing sleep regulation, increased cortisol reactivity and/or brain activity impeding sleep quality, and increased household disorganization [73]. As ACEs are also associated with increased risk for ADHD [74,75], this highlights the need for screening, prevention, and early intervention efforts, such as perinatal mental health and intimate partner violence screenings, school and pediatrician-based child screening, interventions aimed at improving parent-child interactions, family therapy, and interventions which foster emotional resilience [76].

Interestingly, premature birth was associated with less irregular bedtime in the adolescent group. Although speculative, it is possible that premature birth and potential associated medical or neurodevelopmental complications may lead to a pattern of greater parental involvement and monitoring at bedtime due to parental concern for child wellbeing. Additionally, headache or migraine was associated with greater bedtime irregularity among adolescents, in particular. This finding is likely attributed to pain-related bedtime resistance [77] and may suggest the value of stress management and lifestyle changes (e.g., diet) or cognitive-behavioral therapy for headache or migraine to improve bedtime regularity.

4.6. Alternative contributors

Beyond the influence of the aforementioned indicators of bedtime irregularity and sleep insufficiency, disruption to the circadian system, which supports sleep-wake stability, provides an alternate source of impaired sleep in ADHD [78]. Circadian phase delays, known to contribute to difficulties falling asleep and maintaining a consistent bedtime and sleep schedule, may partially account for adverse bedtime and sleep outcomes in children with ADHD ([79–81]), though it is noted that studies have not yet examined circadian phase in adolescents with ADHD [82]). Further, it is possible that ADHD-related deficits in executive function (e.g., difficulties organizing, sustaining attention, planning) may also adversely affect bedtime regularity and sleep sufficiency through procrastination, lost time to playing or social media-related distractions, difficulties managing the time associated with extracurricular demands, and poor homework productivity for example (, [83]). Future empirical evaluation of the influence of circadian disruption on sleep in adolescents with ADHD in particular, and the role of executive functioning deficits in sleep in children with ADHD broadly is needed ([83]; [82]).

4.7. Strengths and limitations

Study strengths include the sizeable nationally-representative sample, matched control group, applicability across childhood with additional stratification by age group, breadth of indicators, and inclusion of a less-often studied sleep outcome – bedtime regularity. Despite strengths, certain limitations must be acknowledged. Sleep variables do not capture weekend sleep, which is important as it is associated with later bedtimes relative to weekdays 84,85. In addition, the cross-sectional data preclude the ability to infer causality, and bidirectional associations are likely. Also, reliance on parental report of child sleep introduces reporter bias, as parent knowledge of adolescent bedtimes in particular may be limited [67]. Additionally, future investigations in older children could benefit from inclusion of additional co-occurring psychiatric disorders (e.g., bipolar disorder, eating

disorders, and substance use disorders) [86]. The screen time variable does not assess device type. Phones, laptops, and gaming devices are more strongly associated with sleep disturbance, while television has mixed associations with sleep outcomes in children and adolescents [21, 87]. Also, individual sleep needs vary and we lack objective quantification of sleep sufficiency. Finally, sleep outcomes were assessed with single-item measures, which may have lower or uncertain reliability and provide a partial assessment of constructs of interest [88]. Future investigations should validate these single-item sleep measures against sleep diary and objective sleep measures (e.g., actigraphy).

4.8. Conclusion

Child ADHD was associated with sleep insufficiency and bedtime irregularity in a nationally-representative sample, confirming and expanding upon prior findings. Findings highlight the role of Black race and screen time in particular, in addition to poverty, ADHD severity, depression, and screen time in sleep insufficiency and bedtime irregularity. Findings also draw attention to ACEs as a distinct indicator of sleep insufficiency, and behavioral or conduct problems, female sex, and absence of both ADHD medication use and ASD as distinct indicators of bedtime irregularity. Age-stratified results were similar but showed that the adolescent (12-17-year-old) group drove associations between most indicators (i.e., chronological age, poverty level, ADHD severity, depression, behavioral or conduct problems, absence of ASD) and bedtime irregularity. In adolescents, unique findings were that headache or migraine was associated with greater bedtime irregularity and premature birth was associated with less bedtime irregularity. Among 3-11-year-old children, anxiety was associated with less insufficient sleep. Future studies should examine the underlying mechanisms driving these associations in the context of child ADHD. Further, longitudinal studies are needed to understand directionality of associations between ADHD symptomatology, psychiatric co-occurring disorders, medication use, and multiple indices of sleep disturbance in children with ADHD over time. Findings underscore the importance of a comprehensive approach to management of sleep problems in children with ADHD. Tailored interventions and/or prevention to mitigate sleep disturbance should account for sociodemographic context along with psychiatric co-occurring disorders and screen use.

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CRediT authorship contribution statement

Talia Y. Leman: Writing – review & editing, Writing – original draft. **Sophia Barden:** Writing – review & editing. **Valerie S. Swisher:** Writing – review & editing, Formal analysis. **Daniel S. Joyce:** Writing – review & editing. **Katherine A. Kaplan:** Writing – review & editing. **Jamie M. Zeitzer:** Writing – review & editing. **Sandra K. Loo:** Writing – review & editing. **Emily J. Ricketts:** Writing – review & editing, Supervision, Project administration, Investigation, Funding acquisition, Formal analysis, Conceptualization.

Declaration of competing interest

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.sleep.2024.06.015.

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