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Last Night's Sleep in Relation to Academic Achievement and Neurocognitive Testing Performance in Adolescents with and without ADHD

Caroline N. Cusick, BS[1]

Paul A. Isaacson, MA[1]

Joshua M. Langberg, PhD[2]

Stephen P. Becker, PhD[1,3,4]

[1] Division of Behavioral Medicine and Clinical Psychology, Cincinnati Children's Hospital Medical Center, Cincinnati, OH, USA
[2] Department of Psychology, Virginia Commonwealth University, Richmond, VA, USA
[3] Department of Pediatrics, University of Cincinnati College of Medicine, Cincinnati, OH, USA
[4] Address correspondence to Stephen P. Becker, Cincinnati Children's Hospital Medical Center, Cincinnati, OH 45229, USA. Phone: 513-803-2066. Email: stephen.becker@cchmc.org

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Abstract

Objectives/Background: Objectives were to (1) examine previous night's sleep in relation to next day performance on standardized academic achievement and neurocognitive assessments in adolescents, and (2) explore whether previous night's sleep is differentially associated with testing performance for adolescents with and without attention-deficit/hyperactivity disorder (ADHD).

Participants/Methods: Participants were 300 adolescents (ages 12-14 years; 55% male). Approximately half (53.6%) were diagnosed with ADHD. Adolescents provided ratings of their previous night's sleep quality, sleep duration, and number of night wakings and were administered standardized tests of processing speed and working memory, as well as word reading, numerical operations, and math fluency academic achievement.

Results: In analyses controlling for sex, race, medication use, time of testing, and ADHD group status, more night wakings the previous night were associated with significantly lower numerical operations and math fluency achievement scores and marginally lower working memory scores. Previous night's sleep was not associated with processing speed or reading achievement. ADHD status did not moderate sleep in relation to academic/neurocognitive performance. Participants reporting ≥2 night wakings the previous night had slightly over half a standard deviation lower scores on average compared to participants reporting 0 night wakings.

Conclusions: This preliminary study suggests that previous night's wakings are associated with poorer mathematics performance the next day, regardless of ADHD status. This may be due to the detrimental effect of interrupted and fragmented sleep on attention and executive control. These findings have implications for clinicians and educators when considering contextual factors that may impact academic and neurocognitive testing performance.

Keywords: adolescence; attention-deficit/hyperactivity disorder; math; processing speed; reading; sleep; working memory

Highlights

- More night wakings the previous night were associated with lower math achievement scores.
- Night wakings were marginally associated with lower working memory scores.
- Previous night's sleep was not associated with processing speed or reading achievement.
- ADHD status did not moderate sleep in relation to academic/neurocognitive performance.
- Assessing and considering previous night's sleep may be important in testing evaluation.

Introduction

Sleep problems negatively affect cognitive and academic functioning in youth (Gradisar et al., 2008; Wolfson & Carskadon, 2003). For example, studies examining objective measures of sleep have found that sleep deprivation can also impact psychomotor vigilance and working memory (de Bruin et al., 2017). Perhaps due to rapid developmental changes in the prefrontal cortex, poor sleep is particularly detrimental for academic performance in early adolescence (Dewald et al, 2010). However, most studies have looked broadly at sleep in relation to school performance and relied on self-report ratings of performance (Dewald et al., 2010). There is some indication from nonclinical samples that school performance (Gillen-O'Neel et al., 2013), working memory (Könen et al., 2015), and psychomotor vigilance (Neylan et al., 2010) are impacted by the prior night's sleep. However, several of these studies were conducted in school-aged children (Könen et al., 2015) or adults (Neylan et al., 2010), leaving it largely unclear whether previous night's sleep impacts testing performance the following day for adolescents, a population that frequently obtains insufficient or poor sleep (Crowley et al., 2018), as well as increased intraindividual variability of sleep/wake patterns (i.e., night-to-night variability) (Becker et al., 2017). Examining prior night's sleep in relation to next day's testing performance has important clinical implications for psychoeducational and neuropsychological assessment.

The association between previous night's sleep and testing performance may vary based upon the characteristics of the youth being evaluated. Adolescents with attention-deficit/hyperactivity disorder (ADHD) have poorer sleep than their typically developing peers (Becker, in press; Lunsford-Avery et al., 2016) and are also frequently referred for testing and re-evaluations linked to school services (e.g., Individual Education Plans [IEPs]). Sleep quality, sleep duration, and number of night wakings have been identified in previous research with school-aged children as sleep domains associated with cognitive functioning (Könen et al., 2015; Gruber et al., 2010; Sadeh et al., 2002). However, no study has examined the previous night's sleep in relation to next day test performance in adolescents with ADHD. Accordingly, the present study (1) examined how previous night's sleep (duration, quality, and wakings) is associated with next day performance on academic achievement and neurocognitive assessments in adolescents, and (2) explored whether previous night's sleep was differentially associated with performance for adolescents with and without ADHD.

Methods

Participants

Participants were 300 adolescents (165 male, 135 female) in eighth grade (ages 12-14 years). The original sample consisted of 302 participants, however, two participants that either completed testing at a different location or did not complete the last night's sleep items at the study visit were excluded from analyses. Approximately half of the participants (53.6%; *n*=160) were diagnosed with ADHD. Most participants were White (81.7%), with remaining participants Black (5.3%), Asian (4.7%), American Indian/Alaska Native (0.3%), or Biracial/Multiracial (8.0%); 4.7% of participants identified as Hispanic/Latino. All participants had an estimated IQ ≥80 (Range=81-148; *M*±*SD*=107.00±13.42) based on the *Wechsler Abbreviated Scale of Intelligence, Second Edition* (WASI-II; Wechsler, 2011).

Procedures

All procedures were approved by an Institutional Review Board. Participants were recruited during the fall semester of their eighth-grade year at two sites in the United States. Parents who contacted the investigators in response to recruitment activities through local schools completed an eligibility screening. Those meeting the screening criteria were scheduled for an evaluation to determine eligibility. We aimed to recruit an approximately equal number of adolescents with and without ADHD. To be eligible for the ADHD group, participants had to meet full DSM-5 diagnostic criteria for either ADHD Predominantly Inattentive Presentation or ADHD Combined Presentation based on the *Parent Children's Interview for Psychiatric Syndromes* (P-ChIPS; Weller, Weller, Fristad, Rooney, & Schecter, 2000). To be eligible for the comparison group, participants were required to have fewer than four symptoms of ADHD in each domain (i.e., inattention and hyperactivity/impulsivity) on the P-ChIPS. To be eligible for either group, participants had to have an estimated IQ ≥80, take core classes in a regular education setting, and could not have a diagnosis of autism, bipolar disorder, a dissociative disorder, a psychotic disorder, or an organic sleep disorder per parent report on a phone screen.

Measures. Adolescents completed a form created for this study about their sleep the night before the assessment visit. Specifically, adolescents were asked to provide an estimate of their sleep duration as well as ratings of sleep quality and night wakings. The sleep duration item ("*How many hours of actual sleep did you get last night? This number may be different than the number of hours you spent in bed*") was queried in an open-ended format. Sleep quality ("*How would you rate last night's sleep overall?*") was rated on a five-point scale (*0=Very good; 1=Fairly good; 2=Okay; 3=Fairly bad; 4=Very bad*). Night wakings ("*After falling asleep, how many times did you wake up during the night last night?"*) was assessed on a six-point scale (0; 1; 2; 3; 4; 5 or more). Additionally, participants were asked whether (yes/no) they took any medication (e.g., medication for ADHD, another psychiatric disorder, allergies, headache) on the day of testing ("*Did you take any medication today?*") and this variable was used as a covariate in analyses.

Adolescents were administered the Word Reading, Numerical Operations, and Math Fluency subtests of the *Wechsler Individual Achievement Test–Third Edition* (WIAT-III; Wechsler, 2009) to measure academic achievement. The Processing Speed and Working Memory scales of the *Wechsler Intelligence Scale for Children–Fourth Edition* (WISC-IV; Wechsler, 2003) were also administered. See Supplemental Materials for additional details regarding these tests and evidence for their reliability and validity.

Analyses

Intercorrelations among study variables were conducted. Hierarchical regression analyses were then run to test whether previous night's sleep was associated with test scores above and beyond sex, race, ADHD group status, medication use on the day of testing, and whether testing was conducted during school hours or after 4pm. All covariates were entered on Step 1, followed by the three sleep variables on Step 2. We also explored whether ADHD status moderated any associations between sleep and test performance. Finally, for significant effects, we examined standardized test scores at varying levels of sleep difficulties using one-way analysis of variance (ANOVA).

Results

Descriptive statistics and intercorrelations among study variables are provided in Table S1. Neither sleep duration nor sleep quality were significantly correlated with any of the testing outcomes, though more night wakings was significantly correlated with lower working memory (p=.02), numerical operations (p=.002), and math fluency (p < .001) scores.

Results of the regression analyses are summarized in Table 1. Having an ADHD diagnosis remained significantly associated with all testing outcomes (ps<.001). Above and beyond covariates and the variance accounted for by sleep duration and sleep quality, night wakings remained associated with significantly lower numerical operations (p=.02) and math fluency (p<.001) scores, and marginally associated with lower working memory scores (p=.07). None of the last night's sleep domains were associated with processing speed or basic reading performance. Further, ADHD status did not interact with any of the sleep domains in predicting test scores[1].

To further examine the impact of night wakings on mathematics achievement (numerical operations and math fluency), we examined test scores for participants reporting 0, 1, or ≥2 night wakings the previous night (ns = 172, 76, and 52, respectively). Results are displayed in Figure 1, with the full sample used for analyses since there was no interaction by ADHD group status (though given the main effect of group, separate ADHD and comparison lines are also shown). For numerical operations, participants reporting 0, 1, or ≥2 night wakings had mean (SD) standard scores of 104.91 (19.65), 101.36 (19.57), and 96.54 (17.45), respectively. The only significant difference was between participants reporting 0 and ≥2 night wakings (p=.02). Participants

[1] Although the objective of our study was to examine whether ADHD moderated the association between previous night's sleep and testing performance, we also explored whether sex moderated this association, as well as the three-way interaction of sleep, sex, and ADHD status. No evidence was found for sex as a moderator or for a three-way interaction in relation to test scores.

reporting 0 night wakings had a score on average 8.37 points higher than participants reporting ≥2 night wakings, a standard score difference of over ½ SD. For math fluency, participants reporting 0, 1, or ≥2 night wakings had mean (SD) standard scores of 99.24 (16.48), 93.29 (13.17), and 91.10 (12.85), respectively. Participants reporting 0 night wakings had significantly higher math fluency scores than participants reporting either 1 or ≥2 night wakings (*p*s=.01 and .002, respectively). Participants reporting 0 night wakings had a score on average 5.95 points higher than participants reporting 1 night waking and 8.14 points higher than participants ≥2 night wakings, a standard score difference of .40 and .54 SD, respectively.

Discussion

This study examined previous night's sleep in relation to academic and neurocognitive performance the following day in a large sample of adolescents with and without ADHD. We found that more night wakings were significantly associated with lower math achievement scores, with results consistent across both numerical operations and math fluency domains after controlling for a number of relevant variables including sex, ADHD diagnostic status, medication use, and time of the assessment visit. More night wakings were also marginally associated with lower working memory scores. None of these effects were moderated by ADHD diagnostic status, indicating that previous night's sleep impacts performance similarly for adolescents with and without ADHD.

Our findings are in consistent with previous research linking sleep to poorer neurocognitive and academic performance (de Bruin et al., 2017). Particularly in line with our findings, Sadeh and colleagues (2002) found that fragmented sleep "characterized by multiple and/or prolonged night-wakings" (p. 405) may be particularly detrimental for neurobehavioral functioning. Participants in our study who reported more night wakings may have had less opportunity for deeper, more restorative sleep (Sadeh et al., 2002). In contrast, we did not find previous night's sleep duration or sleep quality to be associated with any of the performance domains examined in this study. A recent meta-analysis found that sleep duration was not associated with several aspects of cognitive functioning including processing speed and memory (Short et al., 2018). Further, Gruber et al. (2014) found lower actigraphy-measured sleep efficiency (which is in part calculated based on night wakings) but not sleep duration to be associated with lower grades in healthy school-aged children. Previous studies have linked poorer sleep quality to adolescents' school and achievement performance (Buckhalt et al., 2009; Meijer et al., 2000), making this an important area for further study. Also, none of the sleep domains assessed in this study were associated with processing speed or basic reading. Thus, at least of the sleep domains assessed in this study, more night wakings had the clearest effect on testing performance and this association was clearest for math achievement. Mathematics requires a set of complex cognitive skills, including abstract and logical thinking and the ability to identify patterns in novel situations (see Gruber et al., 2014), and sleep fragmentation related to night wakings may have a particularly detrimental impact on these higher-order cognitive skills.

Strengths of the present study include a large sample, including adolescents with and without ADHD, and multiple measures of academic and neurocognitive performance. However, future research should incorporate objective measures of sleep, such as actigraphy or polysomnography, as well as more nuanced items regarding sleep quality and medication type/dose on the evening preceding testing and the day of testing. It would also be informative for future studies to formally assess sleep disorders per *International Classification of Sleep Disorders—Second Edition (ICSD-2)*. Additionally, longer periods of sleep assessment may shed light on how cumulative sleep loss, rather than simply previous night's sleep, impacts testing performance. Future studies should also incorporate more comprehensive batteries of academic achievement and neurocognition. Nevertheless, our findings indicate that previous night's sleep, and night wakings specifically, may have important clinical implications. Specifically, contextual factors, such as previous night's sleep, may be important to assess and consider when administering and interpreting testing evaluations. This is especially important in populations that are frequently referred for assessments and re-evaluations that are often used to determine school services.

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Table 1

Hierarchical regression analyses examining previous night's sleep in relation to neurocognitive and academic achievement test scores

	Step 1 Model Summary				*Step 2 Model Summary*			
	b	*SE*	*β*	*t*	*b*	*SE*	*β*	*t*
DV: WISC Processing Speed								
Time of testing	.74	1.66	.02	0.44	.82	1.67	.03	0.49
Sex	4.84	1.56	.17	3.11**	4.88	1.56	.17	3.12**
Race	.23	1.95	.01	0.12	-.14	1.97	-.004	-.07
Medication use	3.91	1.86	.13	2.10*	3.89	1.87	.13	2.08*
ADHD status	-11.47	1.73	-.41	-6.62***	-11.12	1.75	-.39	-6.34***
Sleep duration	--	--	--	--	.76	.54	.08	1.40
Sleep quality	--	--	--	--	1.32	1.02	.08	1.29
Night wakings	--	--	--	--	-.82	.72	-.07	-1.14
DV: WISC Working Memory								
Time of testing	3.78	1.76	.12	2.16*	3.91	1.76	.13	2.23*
Sex	-.12	1.64	-.004	-0.07	.04	1.65	.001	0.02
Race	4.86	2.05	.13	2.37*	4.24	2.08	.12	2.04*
Medication use	1.12	1.97	.04	0.57	.99	1.97	.03	0.50
ADHD status	-8.50	1.83	-.30	-4.65***	-7.98	1.85	-.28	-4.32***
Sleep duration	--	--	--	--	.61	.57	.06	1.07
Sleep quality	--	--	--	--	1.19	1.08	.07	1.10
Night wakings	--	--	--	--	-1.36	.76	-.11	-1.79†
DV: WIAT Basic Reading								
Time of testing	3.85	1.48	.15	2.60**	3.94	1.48	.15	2.66**
Sex	-2.61	1.38	-.11	-1.89	-2.48	1.39	-.11	-1.78
Race	.47	1.73	.02	0.27	.03	1.76	.001	0.02
Medication use	1.27	1.66	.05	0.76	1.12	1.66	.04	0.68
ADHD status	-6.29	1.54	-.27	-4.08***	-5.97	1.56	-.25	-3.82***
Sleep duration	--	--	--	--	.13	.48	.02	0.27
Sleep quality	--	--	--	--	.55	.91	.04	0.61
Night wakings	--	--	--	--	-.96	.64	-.09	-1.50

(table continues)

Table 1, *continued*

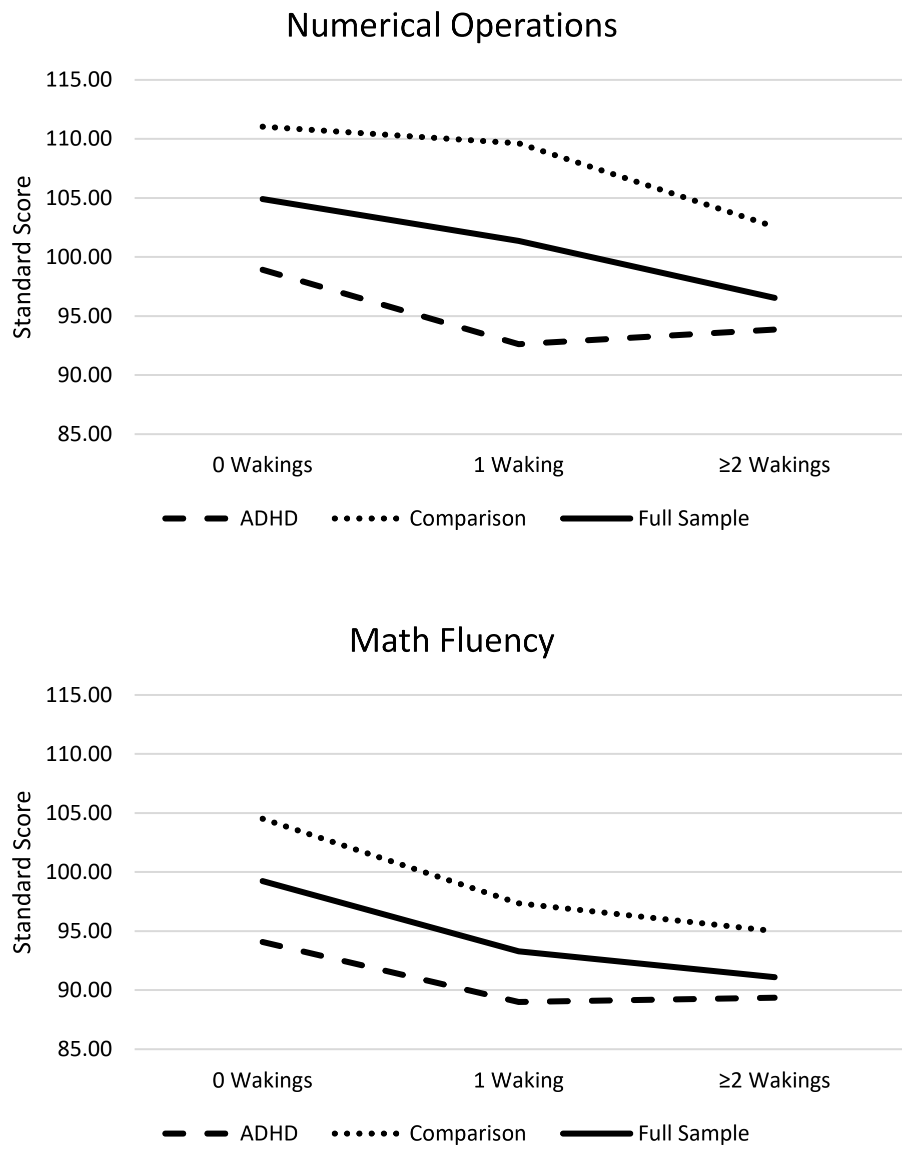
DV: WIAT Numerical Operations								
Time of testing	-4.19	2.36	-.10	-1.78	-4.05	2.35	-.10	-1.73
Sex	-.94	2.20	-.02	-0.43	-.53	2.20	-.01	-0.24
Race	1.12	2.76	.02	0.41	.02	2.78	.000	.01
Medication use	5.30	2.64	.12	2.01*	5.07	2.63	.12	1.92
ADHD status	-15.45	2.45	-.40	-6.30***	-14.48	2.47	-.37	-5.86***
Sleep duration	--	--	--	--	.73	.76	.05	.95
Sleep quality	--	--	--	--	.80	1.44	.03	0.56
Night wakings	--	--	--	--	-2.34	1.02	-.14	-2.30*
DV: WIAT Math Fluency								
Time of testing	-2.59	1.89	-.08	-1.37	-2.41	1.86	-.07	-1.30
Sex	-4.30	1.76	-.14	-2.44*	-3.79	1.75	-.12	-2.17*
Race	-2.29	2.21	-.06	-1.04	-3.56	2.20	-.09	-1.62
Medication use	1..92	2.11	.06	0.91	1.56	2.09	.05	0.75
ADHD status	-11.21	1.97	-.36	-5.70***	-10.18	1.96	-.33	-5.19***
Sleep duration	--	--	--	--	.33	.60	.03	0.55
Sleep quality	--	--	--	--	.45	1.14	.02	0.40
Night wakings	--	--	--	--	-2.71	.81	-.20	-3.36***

Note. For sex, 0 = male, 1 = female. For race, 0 = non-White, 1 = White. For medication use, 0 = no medication taken on day of testing, 1 = medication taken on day of testing. For time of testing, 0 = testing appointment occurred before 4pm, 1 = testing appointment occurred at 4pm or later. For ADHD status, 0 = comparison, 1 = attention-deficit/hyperactivity disorder (ADHD). WIAT = Wechsler Individual Achievement Test, Third Edition. WISC = Wechsler Intelligence Scale for Children, Fourth Edition.

$^{\dagger}p = .07$. $^{*}p < .05$. $^{**}p < .01$. $^{***}p < .001$.

Figure 1

Standardized scores on numerical operations (top panel) and math fluency (bottom panel) between participants reporting zero, one, or two or more night wakings the previous night



SUPPLEMENTAL MATERIALS

Last Night's Sleep in Relation to Academic Achievement and Neurocognitive Testing Performance in Adolescents with and without ADHD

To conserve space in the print version of the journal, this supplement includes (a) additional descriptions of study measures, and (b) intercorrelations and descriptive statistics of study variables (Table S1).

Additional Description of Study Measures

Academic Achievement. Adolescents completed the Word Reading, Pseudoword Decoding, Numerical Operations, and Math Fluency subtests of the *Wechsler Individual Achievement Test – Third Edition* (WIAT-III; Wechsler, 2009). The Word Reading subtest of the WIAT-III assesses the speed and precision of decontextualized word recognition, whereas the Pseudoword Decoding subtest measures one's capacity to pronounce nonsense words. They each provide participants a list of words, which increase in difficulty, to read aloud as quickly and clearly as possible. The administrator records the word the participant reads at the 30-second mark and the subtest concludes when four words in a row are pronounced incorrectly. Participant's scores on the Word Reading and Pseudoword Decoding subtests are combined to determine a Basic Reading score.

To evaluate basic math skills and operations with integers, as well as geometry, algebra, and calculus skills, the Numerical Operations subtest on the WIAT-III was used. This untimed subtest's questions increase in difficulty and the participant is finished when they inaccurately answer four items in a row. Finally, the Math Fluency subtest measures the speed and accuracy of the participant's math computations. The subtest is comprised of three individual assessments (addition, subtraction, and multiplication) and students have 60 seconds to answer as many of the problems as possible (Wechsler, 2009).

Neurocognition. The Symbol Search and Coding subtests of the *Wechsler Intelligence Scale for Children – Fourth Edition* (WISC-IV; Wechsler, 2003) were administered to measure processing speed. Symbol Search subtest has participants identify whether or not two symbols can be found in a group of five symbols. Children are asked to answer as many of the 60 items as possible in a two-minute span. The Coding subtest links the numbers one through nine with unique symbols in a key at the top of the page. With a two-minute time limit, children are asked to draw as many of the corresponding symbols as possible into the empty boxes printed on the rest of the page.

The Digit Span and Letter-Number Sequencing subtests of the WISC-IV were administered to measure working memory. The Digit Span subtest has two parts, Digit Span Forward and Digit Span Backward. Digit Span Forward asks children to repeat numbers in the same order as the administrator reads them aloud, whereas Digit Span Backward asks participants to repeat numbers in the reverse order that the administrator reads them. The Letter-Number Sequencing subtest has the participant listen to the examiner read a series of random numbers and letters. The child is then asked to repeat the numbers first in chronological order, then repeat the letters in alphabetical order. Both the Digit Span and Letter-Number Sequencing subtests are untimed (Wechsler, 2003).

Table S1

Intercorrelations and descriptive statistics among study variables

Variable	1	2	3	4	5	6	7	8	9	10	11	12	13
1. Sex	--												
2. Race	-.09	--											
3. Medication use	-.05	.06	--										
4. Time of testing	.15**	-.07	.09	--									
5. ADHD status	-.20***	-.06	.47***	.07	--								
6. Sleep duration	.01	.01	-.11	.02	-.13*	--							
7. Sleep quality	.06	-.02	.05	-.03	.07	-.29***	--						
8. Night wakings	.08	-.19**	.004	.06	.13*	-.09	.35***	--					
9. Processing speed	.25***	.02	-.07	.03	-.38***	.10	.02	-.08	--				
10. Working memory	.06	.15*	-.09	.09	-.28***	.09	-.01	-.14*	.36***	--			
11. Basic reading	-.04	.03	-.06	.12*	-.21***	.04	-.03	-.11	.23***	.55***	--		
12. Numerical operations	.03	.06	-.07	-.12*	-.34***	.09	-.05	-.18**	.51***	.50***	.40***	--	
13. Math fluency	-.08	-.01	-.12*	-.12*	-.31***	.08	-.08	-.23***	.56***	.41***	.39***	.65***	--
Mean	--	--	--	--	--	7.77	1.15	0.74	97.18	99.69	103.94	102.56	96.32
SD	--	--	--	--	--	1.45	0.81	1.13	14.15	14.26	11.78	19.46	15.45
Minimum	--	--	--	--	--	1	0	0	62	54	66	40	61
Maximum	--	--	--	--	--	12	4	5	141	144	137	160	133

Note. For sex, 0 = male, 1 = female. For race, 0 = non-White, 1 = White. For medication use, 0 = no medication taken on day of testing, 1 = medication taken on day of testing. For time of testing, 0 = testing appointment occurred before 4pm, 1 = testing appointment occurred at 4pm or later. For ADHD status, 0 = comparison, 1 = attention-deficit/hyperactivity disorder (ADHD).
$^{*}p < .05$. $^{**}p < .01$. $^{***}p < .001$.