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SCIENTIFIC INVESTIGATIONS

The associations of insomnia symptoms with daytime behavior and cognitive functioning in children with attention-deficit/hyperactivity disorder

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Study Objectives: The current study aimed to examine the association of insomnia symptoms with daytime behavior and cognitive functioning in children with attention-deficit/hyperactivity disorder (ADHD).

Methods: Thirty-six children with ADHD and insomnia symptoms, 27 children with ADHD without insomnia symptoms, and 21 age-matched healthy controls were recruited in this study (age range: 6–12 years, 70% male). They were assessed by parent-report questionnaires on insomnia symptoms (Children's Sleep Habits Questionnaire) and ADHD symptoms (Strengths and Weaknesses of ADHD Symptoms and Normal Behavior Scale [SWAN]), and completed a battery of cognitive tests including the Continuous Performance Test (CPT) for sustained attention, Letter-digit test for processing speed, Digit Span forward test and *N*-back task for working memory, Tower of London (TOL) test for planning skills and Bergs Card Sorting Test (BCST) for set-shifting ability.

Results: Children with ADHD and insomnia symptoms had the highest scores on SWAN total and inattention and hyperactivity subscales, followed by children with ADHD without insomnia and healthy controls (all $P < .05$). After controlling for potential confounders, children with ADHD and insomnia symptoms showed poorer performance on the CPT and Letter-digit test as compared with children with ADHD without insomnia and healthy controls (all $P < .05$).

Conclusions: Insomnia symptoms are associated with more severe ADHD symptoms and cognitive impairments in children with ADHD, especially deficits in sustained attention and processing speed. Future longitudinal studies are needed to explore the long-term impacts of insomnia symptoms and the effects of sleep-focused intervention on cognitive functioning in children with ADHD.

Keywords: ADHD, insomnia, sleep, daytime behavior, cognitive functioning, children

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BRIEF SUMMARY

Current Knowledge/Study Rationale: Sleep problems have been linked to more severe attention-deficit/hyperactivity disorder (ADHD) symptoms and impaired cognitive abilities in children with ADHD, but the role of insomnia symptoms in daytime behavior and cognitive functioning in children with ADHD remained unclear. We investigated these associations by comparing children with ADHD and insomnia, children with ADHD without insomnia, and healthy controls.

Study Impact: We found that insomnia symptoms were associated with more severe clinical symptoms and poorer sustained attention and processing speed in children with ADHD. Our results revealed that insomnia might play a role in the manifestation of ADHD symptoms and could potentially have a negative effect on cognitive abilities in children with ADHD, which underscores the importance of addressing sleep problems in a timely manner in this vulnerable group.

INTRODUCTION

Attention-deficit/hyperactivity disorder (ADHD) is one of the most common neurodevelopmental disorders of childhood, affecting approximately 3–5% of children worldwide. It is characterized by inappropriate levels of inattentiveness, hyperactivity, and impulsivity, and is often associated with adverse psychosocial, educational, occupational, and health-related outcomes in the affected children, as well as impaired mental health and quality of life in their family members.[1]

ADHD is often associated with high rates of sleep problems. Insomnia, presented as difficulty in initiating sleep (eg, delayed sleep onset or bedtime refusal) and maintaining sleep (frequent nocturnal awakenings), is a common comorbidity in ADHD, with prevalence rates ranging from 25% to as high as 71%.[2,3] It has been reported that sleep problems were associated with behavioral problems in both typically developing children and children with ADHD. In a large community-based study involving 2,463 children aged 6–15 years, children with sleep problems as measured by the Children's Sleep Habits Questionnaire

(CSHQ) presented with more ADHD-like symptoms, including inattentive, hyperactive, and impulsive behaviors.[4] A cross-sectional study conducted in a sample of 83 children with ADHD showed that sleep problems as measured by the CSHQ were associated with higher levels of parent-reported inattentive and hyperactive problems.[5] In another cross-sectional study of 239 children with ADHD, those with moderate-to-severe sleep problems (based on 1 single parent-report item) showed more severe ADHD symptoms than children with no or mild sleep problems.[3] However, previous studies conducted in children with ADHD only measured sleep problems in general and did not look into whether insomnia symptoms would have an impact on daytime behavior in children with ADHD.

Sleep problems have been often reported in association with impaired cognitive abilities in children, including sustained attention,[6] processing speed,[7,8] working memory,[6] and planning skills and set-shifting ability.[9,10] However, the findings on the effects of sleep problems on cognitive functioning in children with ADHD were mixed, with some showing negative effects of sleep problems (as assessed by CSHQ total score) on attentional functioning (as measured by the Attention Network Test),[11] while others suggesting a lack of effect of sleep problems on attention and executive control skills (eg, as measured by Behavior Rating Inventory of Executive Function).[12] In addition, most of the previous studies were focused on a wide range of sleep problems (eg, as assessed by CSHQ total score), and the research specifically considering insomnia symptoms was scant. One study found that parent-reported insomnia symptoms were associated with an impairment in working memory (as measured by the Working Memory Test Battery for Children) in a group of 7- to 13-year-old children with ADHD (n = 189).[13] While this study provided some evidence suggesting the negative effects of insomnia on working memory in children with ADHD, it was limited by the lack of a control group and not taking into account other potential confounding factors, such as ADHD symptoms and the use of medication(s). One of the most common side-effects of stimulant medications is insomnia,[14] while melatonin and alpha-adrenergic agonists (eg, clonidine) have been demonstrated to be effective in reducing sleep-onset latency in children with ADHD.[15,16] Medications commonly prescribed in children with ADHD could potentially affect both their sleep and daytime functioning.

Therefore, the current study aimed to determine if daytime behavior and cognitive functioning would be worse in children with ADHD and insomnia symptoms compared with children with ADHD and without insomnia symptoms as well as healthy controls, while considering the effects of a series of potential confounders. In addition, we explored the associations between parent-reported insomnia symptoms (assessed by CSHQ) and cognitive functioning in children with ADHD. We hypothesized that (1) children with ADHD and insomnia symptoms would have more severe ADHD symptoms, and would show worse cognitive functioning as compared with the respective control groups, and (2) insomnia symptoms would be associated with impaired cognitive functioning in children with ADHD.

METHODS

Procedures and participants

The following 3 groups of children were recruited: (1) children with ADHD and insomnia symptoms, (2) children with ADHD and without insomnia symptoms, and (3) healthy controls. Informed written consent was obtained from the participating families. Eligible participants were assessed by parent-report questionnaires and a battery of cognitive tests administered by trained research assistants who were blinded to the group allocation. All of the computerized cognitive tests were implemented using the Psychology Experiment Building Language (PEBL) platform. PEBL version 0.14 was installed in a Samsung laptop computer running the Microsoft Windows operating system (Microsoft Corporation; Redmond, WA, USA). The screen resolution was set to 1366 × 768 pixels, and the "Full screen" option box was checked (screen size: 15.6 inches). All of the tasks were administered in each child by a trained research assistant in a quiet room without parental presence. Six neurocognitive tests were administered: Continuous Performance Test (CPT) for sustained attention, Letter-digit test for processing speed, Digit Span forward test and *N*-back task for working memory, Tower of London (TOL) test for planning skills, and Bergs Card Sorting Test (BCST) for set-shifting ability. All of the study participants were instructed to take their prescribed medications as usual, if any, on the day of completing cognitive tests. Ethical approval was obtained from the Human Research Ethics Committee (Reference No.: EA1903023) at the University of Hong Kong and Joint Chinese University of Hong Kong–New Territories East Cluster Clinical Research Ethics Committee (Reference No.: 2016.549).

Recruitment of children with ADHD

Potential families with a child with ADHD were recruited between December 2016 and December 2019 from any of the following sources: (1) referrals from attending psychiatrists at the child psychiatric clinic of a local hospital; (2) invitation letters were sent to the special educational needs coordinators (SENCOs) of 112 local primary schools (the SENCOs were invited to distribute the research posters to children with ADHD individually); (3) research posters were sent to the local self-help groups of parents of children with ADHD.

Parents of children with ADHD who were interested in this study were invited to either register for this study online or contact the research assistant for the registration. A brief assessment was first conducted over the phone to ascertain their eligibility (ie, whether the child was clinically diagnosed with ADHD by a health care professional, such as a child psychiatrist). Suitable families were subsequently invited to attend a clinical interview. The Diagnostic Interview Schedule for Children–Version IV (DISC-IV, Chinese version)[17] was administered during the interview to ascertain the child's ADHD diagnosis. DISC-IV was validated locally showing good psychometric properties (test-retest reliability for ADHD: $\kappa = 0.75$).[17] For those children with a diagnosis of ADHD, they were further assessed by parent-report questionnaires on insomnia and ADHD symptoms. They were also administered a battery of cognitive tests using

a standardized administration protocol by trained examiners. Demographic data (age, sex) and the use of medication for ADHD were also recorded.

A child was included in the ADHD group (with or without insomnia symptoms) if he/she met the following inclusion criteria: (1) aged between 6 and 12 years and (2) having a diagnosis of ADHD (any subtype) as confirmed by the DISC-IV. Children were excluded if they met any of the following conditions:

1. Having a serious medical condition (eg, severe cerebral palsy) or intellectual disability
2. Having a neurological and/or medical condition that could potentially have an effect on the child's sleep (eg, epilepsy, endocrine disorders, traumatic injury)
3. Having a clinical diagnosis of other neurodevelopmental disorders (eg, autism spectrum disorder)
4. Having impaired vision or hearing deficit
5. Having a clinical diagnosis of sleep disorders other than insomnia (eg, sleep-disordered breathing, restless legs syndrome/periodic limb movements, circadian rhythm sleep-wake disorders). To further exclude those children with possible sleep apnea, we also excluded those children who scored frequently (5–7 times per week) on CSHQ item 29 (stops breathing while sleeping) and item 30 (snorts and gasps during sleep).
6. Receiving specialized help for their sleep problems from a psychologist or at a specialized sleep clinic

Two groups of children with ADHD were recruited in the present study—that is, children with ADHD and with vs without insomnia symptoms. Parents were asked in the screening interview whether their child experienced sleep problems, including "difficulty initiating sleep, resisting going to bed, difficulty maintaining sleep, or early morning awakening" in the past 4 weeks. If affirmative, they were further asked to rate the overall severity of the problem as mild, moderate, and severe. No specification of the frequency associated with these 3 levels of sleep difficulty was given to the parents when they were asked to rate the severity. The children were subsequently classified into the ADHD with insomnia group if the rating was either "moderate" or "severe," and were classified into the ADHD without insomnia group if the rating was either "none" or "mild." While these 2 items were used to differentiate children with and without insomnia, the sleep symptoms described in the question were based on the diagnostic criteria of insomnia according to the *International Classification of Sleep Disorders*[18] and in line with a consensus definition of pediatric insomnia by the National Sleep Foundation.[19] This question has also been previously used in several studies to assess insomnia in children in the general population,[20] as well as in children with ADHD.[3]

Recruitment of healthy normal controls

A group of age-matched healthy children were recruited from a local primary school and matched with children with ADHD in a ratio of 1:3 to ensure statistical power for analysis while considering the practical difficulty in recruiting child participants in the local context. Healthy controls were also assessed using the same set of parent-report questionnaires on sleep and ADHD symptoms and the same battery of cognitive tests administered in the children with ADHD, after confirming their study eligibility and obtaining the informed consent from their parent/guardian. Criteria for inclusion as a healthy control included the following: (1) absence of any prominent medical problems, (2) free of any diagnosed neuropsychiatric disorder, (3) absence of diagnosed sleep problems (eg, insomnia, sleep-disordered breathing, restless legs syndrome, periodic limb movement disorder, circadian rhythm sleep-wake disorders), (4) not taking any medication, and (5) absence of visual impairment or hearing deficit.

Measures

Measure of ADHD symptoms

The Strengths and Weaknesses of ADHD Symptoms and Normal Behavior (SWAN)–parent report is an 18-item questionnaire for the assessment of the severity of ADHD symptoms. SWAN has been validated locally for use in Chinese children in Hong Kong.[21] Parents were asked to compare their child's inattention and hyperactivity behaviors with children of the same age using a 7-point scale. Scores range from –3 (far better than peers) to +3 (far worse than peers), with 0 denoting average behavior. Higher scores represent more severe ADHD behaviors. The total scale score had excellent internal consistency (Cronbach's alpha = 0.90), test-retest reliability, and good discriminant validity in differentiating an ADHD clinic sample from a community sample.[21]

Sleep measures

The CSHQ is a commonly used parent-report measure to assess sleep symptoms in children aged 4–12 years.[22] CSHQ consists of 33 items to evaluate a child's sleep behavior over the past week (Cronbach's alpha = 0.79). Items are rated on a 3-point scale to indicate the frequency of each sleep behavior: "usually/five to seven times per week," "sometimes/two to four times per week," and "rarely/zero to once per week." The CSHQ total score is the sum of the 33 questions and ranges from 33 to 99. Three key domains of the CSHQ that represent the major presenting symptoms of insomnia in this age group were used for analysis: Bedtime Resistance (6 items; score range: 6–18), Sleep Onset Delay (1 item; score range: 1–3), and Night Wakings (3 items; score range: 3–9). As sleep duration is generally not included as a criterion to define insomnia, and sleep duration subscale score in the CSHQ was calculated as the sum of 3 items (sleeps too little, sleeps the right amount, and sleeps the same amount each day), which might not fully reflect the child's actual sleep duration, the sleep duration subscale score was not included as part of the analysis in the assessment of insomnia in the present study.

Measures of cognitive performance

The following tests were chosen because they could potentially capture different aspects of neurobehavioral deficits that were expected to be sensitive to the effect of sleep deficits and have been used in previous studies.[10] The CPT, which is based on the Conners' Continuous Performance Test version II, was adopted to measure children's sustained attention (ie, an ability to continuously maintain attentional focus under the conditions of low

stimulation and over a prolonged period of time). The Letter-digit test was used for measuring visual-motor processing speed, which is a speed-dependent task that involves visual scanning, attention, and visual-motor processing speed. The Digit Span forward test was used to measure working memory, which emphasizes short-term memory storage. The *N*-back task was used to measure visual working memory. The TOL paradigm was used to measure planning skills in the current study because of its applicability for use with young children.[23] The BCST (64-trial version) was used to assess set-shifting ability.[24] Detailed descriptions of these cognitive tests can be found in **Table 1**.

Statistical analysis

The demographic and sleep characteristics among the 3 groups (ADHD with insomnia group, ADHD without insomnia group, and healthy control group) were compared using chi-square test for categorical variables and one-way analysis of variance (ANOVA) for continuous variables. A multivariate analysis of covariance (MANCOVA) model was constructed to compare ADHD symptoms (as assessed by SWAN) among the 3 groups, with ADHD symptoms as the dependent variable and groups as the independent variable. On the basis of the previous reports of the factors potentially associated with ADHD symptoms and cognitive functioning,[25,26] as well as the results of the univariate analyses, age, sex, and ADHD medication on assessment were included as the covariates in the model. In consideration of the potential confounding effect of ADHD symptoms on cognitive functioning, SWAN total score was further controlled as a covariate in the MANCOVA models when examining the group differences in cognitive functioning. Post hoc analyses were further performed using Bonferroni correction where appropriate. Multiple linear regressions were used to analyze the associations of CSHQ scores with cognitive performance in children with ADHD. The following potential covariates were

Table 1—Summary of cognitive function measures.

Cognitive Abilities	Task	Procedure	Indices
Sustained attention	Continuous Performance Test (CPT)	Over the course of the test (14 minutes), the child was asked to press the spacebar as quickly as possible in response to every signal except for the letter X presented on the screen.	Average reaction time for correct responses, errors of omission, errors of commission
Visual-motor processing speed	Letter-digit test	Nine letters and digits were paired on the top of the screen and the child was requested to press the digits on the keyboard corresponding to a test set of the 9 letters presented in a mixed order. For each letter, the child was required to press the corresponding number on the keyboard as quickly and accurately as possible. The test consisted of 30 trials and took approximately 3 minutes to complete.	Reaction time, the number of correct responses
Working memory	Digit Span forward test	The child was asked to recall the digits presented and to repeat the sequence of the digits in the exact order as presented by pressing the numbers on the computer keyboard.	The length of the longest digit list successfully recalled, the sum of the number of correctly recalled words
Working memory	*N*-back task	The child was asked to respond to the stimulus if the target was identical to the one immediately preceding it (1-back), identical to the one presented 2 trials back (2-back), and identical to the one presented 3 trials back (3-back).	*d*-Prime, which was calculated from hit rate and false alarm rate, using the following formula: d prime = Z score for hit rate – Z score for false alarm rate
Planning skills	Tower of London (TOL) test	Three disks (red, green, and blue) were shown in each trial. The child was asked to move the disks from the original configuration to match the configuration shown on the top of the screen, in a minimum number of moves.	Total score, average response latency for the first move (planning time), average completion time for each trial
Set-shifting ability	Bergs Card Sorting Test (BCST; 64-trial version)	The child was asked to sort 64 cards into 1 of 4 piles based on a rule (color, shape, number) that changed after 10 cards had been successfully matched (rule and changes unknown to the child). Visual feedback ("correct" or "incorrect") regarding whether the cards were matched correctly was provided after each card was sorted.	The percentage of correct responses, perseverative responses, perseverative errors, the number of trials required to complete the first category, and the number of categories completed

selected and included on the basis of the univariate analyses ($P < .2$) and previous reports of their associations with sleep and daytime functioning, including age, sex, ADHD medication on assessment, and the severity of ADHD symptoms. Statistical significance was set at $P < .05$. All of the analyses were conducted using SPSS software version 24.0 (IBM Corporation, Armonk, New York).

RESULTS

Sample characteristics

A total of 84 participants (ie, 36 children with ADHD and insomnia, 27 children with ADHD without insomnia, and 21 healthy controls) were recruited. **Table 2** shows the comparisons of demographic and sleep characteristics between groups. No significant differences were found in age and sex among the 3 groups. Among the children with ADHD, although the regular use of medication for ADHD management was similar between the 2 groups [66.7% vs 66.7%, $\chi^2(1) = 0$, $P = 1$], there were more children without insomnia taking ADHD medication on the day of completing cognitive tests than those with insomnia [66.7% vs 27.8%, $\chi^2(1) = 9.450$, $P = .002$]. In the children with ADHD and insomnia group, 3 used melatonin, while none in the ADHD without insomnia group used it. Children with ADHD taking medication did not differ from those not taking medication on the day of testing in their cognitive performance on all of the tasks except for processing speed (reaction time: 2580.46 ± 159.03 ms vs 3147.76 ± 146.19 ms; $P = .011$).

Comparison of parent-reported sleep measure

Children with ADHD and insomnia showed the highest CSHQ Total score, followed by children with ADHD without insomnia and healthy controls (see **Table 2**; all $P < .05$). Children with ADHD and insomnia had higher scores on CSHQ Bedtime Resistance, Sleep Onset Delay, and Night Wakings subscales than children with ADHD without insomnia and healthy controls (all $P < .05$), with no significant differences between the latter 2 groups (all $P > .05$).

Comparison of ADHD symptoms across groups

After controlling for the effects of age, sex, and ADHD medication on assessment, a significant main effect of groups was evident for ADHD symptoms (as assessed by SWAN) as tested by MANCOVA, Wilk's $\Lambda = 0.462$, $F(6, 152) = 2.92$, $P < .001$, partial $\eta^2 = 0.321$. Univariate analysis revealed significant differences in SWAN total score [$F(2, 78) = 39.497$, $P < .001$, partial $\eta^2 = 0.503$], SWAN inattentive score [$F(2, 78) = 40.233$, $P < .001$, partial $\eta^2 = 0.508$], and SWAN hyperactivity score [$F(2, 78) = 30.311$, $P < .001$, partial $\eta^2 = 0.437$]. Pairwise comparisons showed that children with ADHD and insomnia had the highest SWAN total score, and inattention and hyperactivity subscale scores, followed by children with ADHD and without insomnia and healthy controls (all $P < .05$; see **Table 3**).

Comparison of cognitive performance across groups

The battery of cognitive tasks were administered in the morning in 42 children (50%) and in the afternoon in the other 42 children (50%). Timing of testing (morning vs afternoon) did not

Table 2—Comparisons of demographic and sleep characteristics between groups.

	ADHD with Insomnia (A) (n = 36)	ADHD without Insomnia (B) (n = 27)	Healthy Controls (C) (n = 21)	ANOVA		
				F/χ^2	P	Post hoc
Demographic characteristics						
Age, y	9.39 ± 1.55	9.70 ± 1.33	9.86 ± 1.82	0.675	.512	
Sex, male, n (%)	26 (72%)	21 (77.8%)	12 (57%)	2.53	.283	
Medication, n (%)	24 (66.7%)	18 (66.7%)	—	0.000	1	
None	12	9	—			
Ritalin (Novartis Pharmaceuticals, Basel, Switzerland)	18	11	—			
Concerta (Janssen Pharmaceuticals, Schaffhausen, Switzerland)	4	7	—			
Strattera (Eli Lilly Pharmaceuticals, Indianapolis, USA)	4	3	—			
Melatonin	3	0	—			
ADHD medication on assessment, n (%)	10 (27.8%)	18 (66.7%)	—	9.450	.002**	A < B
Sleep characteristics						
CSHQ Total score	56.78 ± 6.59	51 ± 6.94	42.95 ± 5.23	31.001	<.001***	A > B > C
CSHQ Bedtime Resistance	10 ± 2.99	8.33 ± 2.86	7.24 ± 1.45	7.794	.001**	A > B = C
CSHQ Sleep Onset Delay	2.19 ± 0.67	1.41 ± 0.64	1.24 ± 0.62	18.592	<.001***	A > B = C
CSHQ Night Wakings	3.86 ± 0.93	3.44 ± 0.8	3.1 ± 0.3	6.734	.002**	A > B = C

Data are presented as mean ± SD unless otherwise indicated. *$P < .05$; **$P < .01$; ***$P < .001$. ADHD = attention-deficit/hyperactivity disorder, ANOVA = analysis of variance, CSHQ = Children's Sleep Habits Questionnaire, SD = standard deviation.

Table 3—Comparisons of ADHD symptoms between groups.

	ADHD with Insomnia (A) (n = 36)	ADHD without Insomnia (B) (n = 27)	Healthy Controls (C) (n = 21)	*F*	*P*[a]	Bonferroni-corrected *P*		
						A vs B	A vs C	B vs C
SWAN total score	1.48 ± 0.79	0.65 ± 1.1	–0.91 ± 0.84	30.493	<.001***	.001**	<.001***	<.001***
SWAN inattentive score	1.60 ± 0.80	0.70 ± 1.0	–0.73 ± 1.30	40.233	<.001***	.001**	<.001***	<.001***
SWAN hyperactivity score	1.38 ± 0.94	0.62 ± 01.25	–1.07 ± 0.86	30.311	<.001***	.006**	<.001***	.001***

Data are presented as mean ± SD unless otherwise indicated. **P < .01; ***P < .001. [a]Controlling for age, sex, and ADHD medication on assessment. ADHD = attention-deficit/hyperactivity disorder, SD = standard deviation, SWAN = Strengths and Weaknesses of ADHD Symptoms and Normal Behavior.

have a significant effect on the cognitive outcomes (all $P > .05$). **Table 4** shows the results of the comparisons of cognitive performance between the groups. After controlling for age, sex, ADHD medication on assessment, and SWAN total score, a significant main effect of groups was evident for CPT performance as tested by MANCOVA, Wilk's $\Lambda = 0.977$, $F(6,150) = 2.92$, $P = .01$, partial $\eta^2 = 0.106$. Univariate analysis revealed significant differences in correct reaction time [$F(2, 77) = 6.17$, $P = .003$, partial $\eta^2 = 0.140$] and omission errors [$F(2,77) = 3.36$, $P = .04$, partial $\eta^2 = 0.081$]. Pairwise comparisons showed that children with ADHD and insomnia had a longer correct reaction time on CPT than children with ADHD and without insomnia ($P = .023$) and healthy controls ($P = .007$). In addition, children with ADHD and insomnia had more omission errors on CPT as compared with healthy controls ($P = .047$). There was a significant main effect of group on the Letter-digit test, Wilk's $\Lambda = 0.847$, $F(4, 152) = 3.25$, $P = .014$, partial $\eta^2 = 0.08$. Univariate analysis revealed a significant difference in reaction time [$F(2, 77) = 14.71$, $P < .001$, partial $\eta^2 = 0.277$]. Pairwise comparisons showed that children with ADHD and insomnia showed a longer reaction time than children with ADHD and without insomnia ($P = .042$) and healthy controls ($P = .011$).

Associations of parent-reported sleep (CSHQ) with sustained attention and processing speed in children with ADHD

As shown in **Table 5**, after controlling for age, sex, ADHD medication on assessment, and SWAN total score, multiple regression analyses showed significant positive associations of omission errors on CPT with CSHQ Total score (standardized [St.] $\beta = 0.29$, $P = .025$) and Bedtime Resistance score (St. $\beta = 0.35$, $P = .008$), as well as a marginally significant association between omission errors and CSHQ Sleep Onset Delay score (St. $\beta = 0.26$, $P = .051$), suggesting that more severe parent-reported sleep problems, especially insomnia symptoms, were associated with poorer sustained attention in children with ADHD. In addition, there was a significant association between mean reaction time on the Letter-digit test and CSHQ Bedtime Resistance score (St. $\beta = 0.32$, $P = .005$), as well as a marginally significant association between mean reaction time and CSHQ Total scores (St. $\beta = 0.19$, $P = .093$), suggesting that more severe parent-reported sleep problems were correlated with slower processing speed in children with ADHD.

DISCUSSION

The current study compared daytime behavior and cognitive functioning in children with ADHD and insomnia symptoms, children with ADHD and without insomnia symptoms, as well as healthy controls. We found that insomnia symptoms were associated with more severe ADHD symptoms and poorer sustained attention and processing speed in children with ADHD. The findings highlight the potential role of insomnia in the manifestation of ADHD symptoms and negatively affecting cognitive abilities (sustained attention, processing speed) in children with ADHD, which might potentially give rise to their frustration,[27] low self-esteem,[28] and academic difficulties.[29]

In this study, we found that insomnia symptoms in children with ADHD were associated with more severe behavioral manifestations of ADHD, including inattention and hyperactivity. This observation was in line with that of previous studies conducted in adults with ADHD, which indicated that insomnia symptoms were significantly associated with ADHD symptomatology, independent of age and sex.[30,31] On the other hand, previous studies that examined the association of sleep problems and daytime behavior in children with ADHD have reported mixed findings. While Vélez-Galarraga et al.[32] demonstrated that greater severity of difficulty falling sleep was associated with higher levels of parent-reported inattentive and hyperactive problems in a group of children with ADHD (n = 126, age range 5–18 years), other studies did not find any association between sleep problems and ADHD symptoms.[33,34] The discrepancy of the findings might be due to the methodological issues, such as the measurement of sleep problems. For example, some studies used the total score of CSHQ as the outcome,[22] which reflects the severity of a wide range of sleep problems—for example, insomnia-related symptoms, sleep-disordered breathing, parasomnias, sleep anxiety, and daytime sleepiness. While sleep-disordered breathing has been shown to be related to more

Table 4—Comparisons of cognitive performance between groups.

	ADHD with Insomnia (A) (n = 36)	ADHD without Insomnia (B) (n = 27)	Healthy Controls (C) (n = 21)	*F*	*P*[a]	Bonferroni-corrected *P*		
						A vs B	A vs C	B vs C
Sustained attention								
Continuous Performance Test				2.92	.01*			
Correct reaction time, ms	519.08 ± 67.96	449.79 ± 87.82	392.49 ± 66.56	6.166	.003**	.023*	.007**	NS
Omission errors, n	50.14 ± 14.71	30.63 ± 9.87	11.57 ± 8.85	3.364	.04*	NS	.047*	NS
Commission errors, n	34.23 ± 36.72	22.67 ± 6.22	23.59 ± 6	0.678	.51			
Processing speed								
Letter-digit test				3.25	.014*			
Reaction time, ms	3,393.97 ± 1,194.35	2,440.16 ± 490.68	2,174.34 ± 417.84	5.452	.006**	.042*	.011*	NS
Correct responses, n	28.53 ± 2.21	29.34 ± 0.89	29.17 ± 1.1	1.442	.243			
Working memory								
Digit Span forward test				0.81	.518			
Visual attention span	6.78 ± 1.33	6.59 ± 1.69	7.29 ± 1.77	0.781	.462			
Correctly recalled words, n	9.78 ± 2.68	10.15 ± 2.84	10.19 ± 3.76	0.053	.949			
N-back task				0.92	.481			
1-back *d*-prime	5.44 ± 2.06	5.66 ± 1.84	5.94 ± 1.6	0.354	.703			
2-back *d*-prime	3.44 ± 2.24	3.81 ± 1.99	3.17 ± 2.2	0.4	.672			
3-back *d*-prime	1.73 ± 1.47	1.97 ± 1.49	1.72 ± 1.52	1.951	.149			
Executive function								
Tower of London test				0.60	.728			
Total score	19.33 ± 8.13	21.89 ± 4.77	20.14 ± 6.58	0.23	.795			
Planning time, ms	9,206.16 ± 3,822.51	10,165.96 ± 4,501.19	11,645.62 ± 5,221.47	1.521	.225			
Completion time, ms	16,324.05 ± 5,463.79	16,888.81 ± 5,472.42	18,225.95 ± 7,080.8	1.34	.268			
Bergs Card Sorting Test				1.16	.324			
Correct responses, %	63.5 ± 13.43	66.61 ± 11.37	72.62 ± 14.61	2.324	.105			
Category completed, n	2.17 ± 1.03	2.74 ± 1.13	3.14 ± 1.35	1.179	.313			
Perseveration responses, n	20.53 ± 6.68	23.7 ± 8.71	20.14 ± 5.86	1.472	.236			
Perseveration errors, n	11.06 ± 5.36	12.93 ± 5.79	9.33 ± 4.88	2.18	.12			
Number of trials to first category	19.56 ± 10.33	16.11 ± 8.84	16.81 ± 9.9	0.454	.637			

Data are presented as mean ± SD unless otherwise indicated. *P < .05; **P < .01. [a]Controlling for age, sex, ADHD medication on assessment, and SWAN total score. ADHD = attention-deficit/hyperactivity disorder, NS = not significant, SD = standard deviation, SWAN = Strengths and Weaknesses of ADHD Symptoms and Normal Behavior.

severe behavioral manifestations of ADHD,[35] sleep anxiety was not related to the behavioral problems in children with ADHD.[36] Therefore, there is a need to look into specific sleep problems in relation to daytime behavior in children.

In this study, we found that insomnia symptoms, especially parent-reported difficulty in initiating sleep (ie, bedtime resistance and sleep-onset delay), were associated with poor sustained attention in children with ADHD. These findings are in line with the results from the studies conducted in adults with primary insomnia, suggesting a link between insomnia and deficits in sustained attention.[34,37,38] Previous neuroimaging studies have found that adult patients with insomnia showed a reduction in prefrontal cortex activity during wakefulness and altered functional connectivity between the parietal and frontal lobes, which are the cortical structures critical for sustained attention.[39] In addition, abnormal sleep architecture (especially decreased slow-wave sleep) in patients with insomnia has been found to be associated with deficits in executive control of attention.[40] However, there have been mixed findings on the association between insomnia symptoms and sustained attention in children with ADHD, with some studies showing negative effects of sleep problems on sustained attention,[41,42] while others reported no effect.[33,43] The present study was different from previous research in terms of the sample characteristics. For example, previous studies either recruited only boys with ADHD[43] or children with ADHD and comorbid psychiatric disorders.[33] The detailed mechanism underlying the negative effects of insomnia on sustained attention in ADHD has not

Table 5—Associations of parent-reported sleep (CSHQ) with sustained attention and processing speed in children with ADHD (n = 63).

	Continuous Performance Test										Letter-Digit Test				
	Correct Reaction Time					Omission Errors					Mean Reaction Time				
	β	SE β	St. β	*t*	*P*[a]	β	SE β	St. β	*t*	*P*[a]	β	SE β	St. β	*t*	*P*[a]
CSHQ Total score	2.17	1.43	0.19	1.52	.135	1.58	0.69	0.29	2.31	.025*	28.18	16.50	0.19	1.71	.093^
CSHQ Bedtime Resistance	3.19	3.54	0.12	0.90	.372	4.52	1.64	0.35	2.75	.008**	112.05	38.57	0.32	2.91	.005**
CSHQ Sleep Onset Delay	22.05	13.95	0.20	1.58	.119	13.48	6.75	0.26	2.00	.051^	181.57	163.13	0.13	1.11	.27
CSHQ Night Wakings	–7.80	11.52	–0.08	–0.68	.501	–0.88	5.67	–0.02	–0.16	.877	–83.09	133.46	–0.07	−0.62	.536

^*P* < .1; **P* < .05; ***P* < .01. [a]Controlling for age, sex, ADHD medication on assessment, and SWAN total score.
ADHD = attention-deficit/hyperactivity disorder, CSHQ = Children's Sleep Habits Questionnaire, SE = standard error, St. = standardized, SWAN = Strengths and Weaknesses of ADHD Symptoms and Normal Behavior.

been well understood, and future neuroimaging studies would be needed to shed light on the potential mechanisms accounting for these effects. Moreover, future studies using objective measure (eg, polysomnography) are needed to examine the effects of sleep (eg, total sleep duration, sleep efficiency, sleep stages and microstructure) on cognitive functioning in children with ADHD.

Similarly, we found a negative effect of insomnia symptoms (bedtime resistance) on processing speed in children with ADHD. This observation was in line with a previous study reporting a positive association between sleep problems and processing speed in children aged 5–18 years referred for neuropsychological assessment in an outpatient clinic.[42] Previous neuroimaging studies have reported that adult patients with insomnia showed lower thalamic volume and altered diffusivity in the superior longitudinal fasciculus, which were associated with slower processing speed.[44] Few studies have investigated the association between sleep problems and processing speed in children with ADHD. One study conducted in a group of preschool children with ADHD found that reduced processing speed (as measured by Processing Speed Index derived from the Wechsler Preschool and Primary Scale of Intelligence) appeared to be attributable to the symptoms of ADHD rather than to sleep problems.[12] The discrepancy in the findings might be due to the methodological differences between the present study and the previous research—for example, the age of the recruited sample (school-aged children vs preschool children). It remained unclear whether the effects might be age dependent. Further longitudinal studies with a larger sample size across different age strata are recommended to elucidate the role of insomnia in relation to processing speed in children with ADHD from a developmental perspective.

Among the 3 common childhood insomnia symptoms, only bedtime resistance as based on parental report was found to be associated with sustained attention and processing speed in children with ADHD in the current study. Bedtime resistance is a common behavioral sleep problem in childhood in the general population and is also commonly seen in children with ADHD. Children with ADHD often have behavioral problems, such as hyperactivity (eg, unable to sit still, fidgeting) and defiant and aggressive behaviors, which may be linked to their resistance at bedtime as parents/caregivers may find it difficult to establish a regular bedtime routine and settle their child to sleep in the evening.[45] Although polysomnography and actigraphy can objectively provide more accurate estimates of sleep parameters, such as sleep-onset latency and wake-after-sleep-onset (WASO), parental report is often considered as the major source of information when assessing the child's sleep problems. However, some parents may not be fully aware of their child's nighttime sleep (eg actual sleep latency, nighttime awakenings) and may underestimate insomnia symptoms in their child.[46] As such, it may be helpful to consider incorporating both subjective reports (child's self-report and parental report of sleep problems) and objective measures in future studies when measuring the child's sleep, especially in those with ADHD and other neuropsychiatric disorders.

Insomnia symptoms were not found to affect other aspects of executive functioning, including working memory, planning skills, and set-shifting ability in the current sample of children with ADHD. The finding on the lack of significant impairment on short-term working memory as assessed by the Digit Span forward test in children with ADHD and insomnia was similar to that of a previous study conducted in adults, which did not find a significant difference in the performance on the digit span tasks between adults with insomnia compared with healthy sleeper controls.[47] However, another study conducted in a community sample of youths showed negative effects of insomnia on working memory as measured by the Digit Span task, which focused more on working memory storage load, but not on the performance as measured by the *N*-back task, which required more demand on working memory processing load that involved executive functions.[48] The discrepancy in the findings across the studies might be related to the differences in the sample characteristics (eg, children with ADHD vs youths without neuropsychiatric disorders) and the use of different tasks. Moreover, some cognitive abilities (eg, executive function as assessed by TOL test) may be more sensitive to the effects of sleep deprivation per se[49] than insomnia symptoms. Although

some studies found cognitive deficits, especially in the tasks measuring sustained attention, in children with ADHD when compared with those without ADHD,[50] the findings on the performance on the executive function tasks (eg, designed to assess set-shifting ability and planning skills) remained inconsistent. Some previous studies found that children with ADHD made comparable perseverative errors as their typically developing peers on the Wisconsin Card Sorting Test,[51] while children with ADHD showed slower set-shifting ability during the Trail Making Test[52] and poorer performance on the TOL test[53] than healthy controls. It is possible that some of the behavioral tests were not sufficiently sensitive to detect mild cognitive impairments in children.[54] Although we did not find a significant difference in the behavioral performance on several domains of cognitive functioning, it remains unclear whether there might be any underlying neural change associated with insomnia symptoms. In this regard, a previous functional magnetic resonance imaging study has shown that adult patients with insomnia had intact performance on the *N*-back task on a behavioral level, yet demonstrated a reduced activation in the task-related working memory brain regions (eg, frontoparietal regions).[55] Another study also showed impaired inhibitory control as measured by electroencephalography during the cued Go/No Go task in youths with insomnia as compared with healthy sleeper controls, despite their comparable behavioral performance.[56] Future studies should therefore also combine neurophysiological and neuroimaging techniques to better understand the nature of insomnia-related cognitive deficits in children with ADHD.

Our findings on the potential negative effects of insomnia on ADHD symptoms and cognitive functioning underscore the need to address sleep problems in children with ADHD in a timely manner. In this regard, there has been some evidence, albeit limited, to support the effects of sleep-focused behavioral intervention on improving sleep, ADHD symptoms, daily functioning, and working memory in children with ADHD.[57–59] Nonetheless, there is a need for more larger randomized controlled trials with long-term follow-up to assess the effects of sleep-focused interventions on behavioral and cognitive functioning in children with ADHD.

This study was one of the very few studies that explored the effects of insomnia on daytime behavior and cognitive functioning in children with ADHD. A main strength of the present study was the recruitment of age-matched control groups and the consideration of several potential confounders such as age, sex, and ADHD medication use on assessment, which were not fully considered in the previous research. In addition, the objective neurobehavioral assessments in this study covered several domains of cognitive functioning (eg, sustained attention, processing speed, working memory, planning skills, and set-shifting ability), which have been shown to be sensitive to the effect of sleep loss.[10] Nonetheless, there are some limitations to this study. First, this study used a cross-sectional design, limiting the possibility of making causal conclusions between insomnia, daytime behaviors, and cognitive functioning. There is a need for further longitudinal research to examine the direction of the effects for the associations between these variables in children with ADHD. Second, a general question was used to classify children with ADHD with and without insomnia and it did not take the frequency and duration of insomnia symptoms (eg, at least 3 times per week for a duration of at least 3 months) and daytime impairments as based on the *Diagnostic and Statistical Manual of Mental Disorders*, fifth edition, and *International Classification of Sleep Disorders*, third edition criteria into consideration. The CSHQ was used as a major measure of insomnia in this study, but it is generally considered as a screening instrument instead of a diagnostic tool. Future studies may consider using more stringent criteria to define pediatric insomnia. Third, sleep measures in this study were mainly based on parental report, albeit that this is the most commonly used method to obtain information on sleep in children. We excluded children with clinically diagnosed sleep disorders based on parental report, without using polysomnography to confirm potential comorbid sleep disorders. Fourth, while the control group consisted of community-based healthy children recruited from a local mainstream primary school, there was no clinical interview conducted, and the medical history of this control group was based only on parental report.

In conclusion, insomnia symptoms are associated with more severe ADHD symptoms and cognitive impairments, especially deficits in sustained attention and processing speed. Future studies with a longitudinal design are needed to further explore the long-term impacts of insomnia and the effects of sleep-focused intervention on cognitive functioning in children with ADHD.

ABBREVIATIONS

ADHD, attention-deficit/hyperactivity disorder
CPT, Continuous Performance Test
CSHQ, Children's Sleep Habits Questionnaire
SD, standard deviation
St., standardized
SWAN, Strengths and Weaknesses of ADHD Symptoms and Normal Behavior Scale
TOL, Tower of London

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