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Associations between sleep-disordered breathing and behavioral and cognitive functions in children with and without attention-deficit/hyperactivity disorder

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Short running head: SDB and behavior/cognition in children with and without ADHD

Abstract

Objective: This study aimed to investigate the associations between sleep-disordered breathing (SDB) and behavioral and cognitive functions in children with and without attention-deficit/hyperactivity disorder (ADHD).

Methods: A total of 341 children were included (ADHD group: 155, control group: 186; age: 6–10 years). The participants' sleep-related symptoms were assessed using a parent-rated questionnaire, and they were categorized into low- and high-risk SDB groups based on their scores. Behavioral symptoms were assessed using the Behavioral Assessment System for Children, Second Edition (BASC-2), and cognitive sustained attention and inhibitory control were assessed using a computer-based continuous performance test.

Results: In the ADHD group, the high-risk SDB children showed significantly higher scores than the low-risk SDB group in externalizing problems ($F = 4.22$; $p = 0.042$), including hyperactivity ($F = 4.65$; $p = 0.033$) and attention problems ($F = 8.19$; $p = 0.005$), but not internalizing problems. Meanwhile, in the control group, the high-risk SDB children showed significantly higher scores than the low-risk SDB group in internalizing problems ($F = 9.89$; $p = 0.002$), depression ($F = 9.45$; $p = 0.002$) and somatization ($F = 7.83$; $p = 0.006$), as well as in externalizing problems ($F = 7.72$; $p = 0.006$), including hyperactivity ($F = 6.23$; $p = 0.013$), aggression ($F = 5.00$; $p = 0.027$), and conduct problems ($F = 6.79$; $p = 0.010$). Contrary to the behavioral outcomes, none of the attention performance subscale scores showed significant differences between the high- and low-risk SDB groups in either the ADHD or control group.

Conclusions: The present findings suggest that SDB is associated with behavioral problems in children with ADHD and controls, with stronger associations in control children. On the

contrary, SDB has no association with cognitive attention performance. This study extends our understanding of the associations of SDB with behavioral symptoms and cognitive functions in children.

Keywords: sleep-disordered breathing, child, behavior, cognition, attention-deficit/hyperactivity disorder

Introduction

Attention-deficit/hyperactivity disorder (ADHD) is a neurodevelopmental disorder characterized by three core symptoms, namely hyperactivity, impulsivity, and inattention. Cases of ADHD are commonly observed among children and adolescent psychiatry outpatients. With a global prevalence of approximately 5%,[1,2] ADHD is associated with poor academic performance and attainment in childhood and poor occupational productivity in adulthood due to impairment of executive functions.[2,3]

ADHD is highly comorbid with mood and behavioral problems, such as depression, anxiety, aggression, and substance abuse. The prevalence of major depression, multiple anxiety disorder, and oppositional defiant disorder in clinically referred school-aged children with ADHD is reportedly 47%, 33%, and 59%, respectively.[4]

Sleep-related problems are some highly prevalent comorbidities in children with ADHD. These problems include difficulty in falling asleep, bedtime resistance, excessive daytime sleepiness, rhythmic movements during sleep, restless leg syndrome, sleep walking, and night terrors.[5–7] Up to 50% of parents whose children have ADHD reported difficulties with their child's sleep.[6] Therefore, the Diagnostic and Statistical Manual of Mental Disorders, Third Edition,[8] included sleep disturbances as symptoms of ADHD.

Among various sleep-related problems, sleep-disordered breathing (SDB) is one of the most common comorbid conditions in children with ADHD. SDB is a continuum of sleep-related breathing disturbances ranging from mild primary snoring (PS) to severe obstructive sleep apnea (OSA).[9] Indeed, SDB is a common pediatric problem, with the incidence of OSA peaking between 2 and 6 years old, when the tonsils and the adenoids are the largest in size relative to the airway.[10] The reported prevalence of pediatric SDB ranges

from 7% to 22% for PS and from 0.7% to 3.0% for OSA.[9] Two studies reported that the prevalence of SDB was higher in children with ADHD than in those without ADHD (controls), i.e. 50% versus 22% in one study[11] and 56.8% versus 17% in another study.[12]

Several studies have investigated the association between SDB and unfavorable behavioral problems in children. Most pediatric studies on behavioral aspects and OSA have reported an association between OSA and internalizing and externalizing problems, such as hyperactivity, attention deficit, aggressiveness, anxiety, and social and thought problems.[13-17]

Other researchers have investigated the association between OSA and cognitive functions in terms of the overall intelligent quotient (IQ), attention, memory and learning, language, executive functions, and academic performance.[18] A meta-analysis concluded that the intellectual abilities of children with OSA may be impaired, albeit within the normal range; impairments in other cognitive domains remain unclear due to inadequate evidence.[18] Studies evaluating the association between OSA and cognitive function, in terms of attention, have also reported inconsistent findings; some studies have revealed that the attention performance in children with OSA was significantly more impaired than that in the controls.[19,20] However, Halbower et al.[21] showed that children with OSA did not differ from healthy control children in terms of omission and commission errors, despite their lower IQ. Furthermore, Jackman et al.[22] demonstrated that SDB, independent of severity, was associated with poor behavioral outcomes, but not with cognitive performance.

Multiple studies have investigated the associations between SDB and behavioral and cognitive outcomes. However, despite the aforementioned strong associations between ADHD and SDB, most studies have been performed in normal children with no psychopathology of ADHD. Furthermore, to our knowledge, no study has directly compared

the differential associations of SDB with behavioral and cognitive functions between children with and without ADHD. Thus, we aimed to investigate the associations between SDB and behavioral problems and cognitive functions during childhood through a study comprising healthy children and children with ADHD.

Methods

Participants

This study included 341 children, between 6 and 10 years, who participated in a screening for neurodevelopmental disorders conducted in a medium-sized city in South Korea from 2008 to 2010. The screening questionnaires, including the Korean version of the ADHD rating scale (K-ARS) and the autism spectrum screening questionnaire (ASSQ), were distributed to parents or guardians of 30,227 children. From these, 417 children who were screened in 2009 and 2010 on the basis of K-ARS and ASSQ cutoff scores of 19 and 15, respectively, were randomly sampled and invited to participate in this case-control study. The participating children were assessed by a psychiatrist who conducted a diagnostic interview and administered a continuous performance test. Parents of the participating children responded to a questionnaire assessing sleep and behavioral symptoms. After excluding children diagnosed with other psychiatric disorders (autism spectrum disorder; n = 67) and with missing data for the questionnaire on sleep and behavioral symptoms (n = 9), a total of 341 children (ADHD group = 155, control group = 186) were finally included in the analysis. Before inclusion in the study, all of the children and their parents were provided with the rationale for and an explanation of the study, and written informed consent was obtained. The study protocol was approved by the institutional review board of Dankook University

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Measurements

Assessment of SDB

The parents responded to the pediatric sleep questionnaire (PSQ), which was developed to assess multiple sleep-related problems in children.[23] The PSQ contains 70 items with the following scores: "yes" = 1, "no" = 0, and "don't know" = missing. Chervin et al.[23] also suggested the Sleep-Related Breathing Disorder (SRBD) scale, which comprises 22 of the 70 PSQ items, and the average optimal cutoff for identifying pediatric cases of OSA is set at 0.33. The SRBD scale includes the following symptom categories: snoring, breathing problems, sleepiness, and behavioral problems. However, the items included in the behavioral subscale coincide with the items included under ADHD symptoms. Thus, during SDB assessment, we excluded these items and adopted only those that were subjected to the factor of breathing in a previous validation study on the original SRBD scale.[23] Finally, our study used eight items—A2, A3, A4, A5, A6, A7, A24, and A25—corresponding to the breathing factors of the original SRBD scale (including symptom categories of snoring, breathing problems, and mouth breathing). Compared with the other items of the SRBD scale, these items presented a higher odds ratio for the presence of SRBD.[23] A cutoff value of 0.33 was used for identifying the high-risk SDB group.

Assessment of behavior and neuropsychological function

The children's behavioral symptoms were assessed using the K-ARS and the Behavioral Assessment System for Children, Second Edition (BASC-2). The ARS is a parent-rated

assessment tool for identifying ADHD symptoms in children and consists of 18 items rated on a 4-point Likert scale (0–3 points)[24]; the K-ARS was validated by Kim et al.[25] The BASC-2 is a multidimensional parent-rated assessment tool that assesses the internalizing and externalizing behavioral problems of children and consists of 160 items rated on a 4-point Likert scale (0–3 points).[26] The children's cognitive functions were assessed using the Korean version of the ADHD Diagnostic System (ADS), a computer-based continuous performance test.[27] The ADS evaluates the sustained attention and inhibitory control of children using auditory and visual approaches. The children's scores on the BASC-2 and ADS were transformed to T-scores, with higher T-scores indicating unfavorable behavioral characteristics and poor performances.

Statistics

Demographic variables were analyzed using descriptive statistics, χ^2 tests, and independent *t*-tests. Between-group comparisons of the scores on the K-ARS, BASC-2, and ADS subscales were performed by analysis of variance for the crude model and analysis of covariance for the adjusted model. In the analysis of the adjusted model, sex, age, paternal and maternal educational level, and household income level were considered as covariates. To examine the linear association between the SDB scores and behavioral and cognitive function scores, a general linear model was utilized. The analysis was performed with SPSS version 25.0 (IBM Corp., Armonk, NY, USA) for Windows (Microsoft, Redmond, WA, USA).

Results

Participant characteristics

Table 1 shows the characteristics of the participants. Parental education levels differed significantly between the control and ADHD groups. The SDB score (F = –2.10; p = 0.036), daytime sleepiness score (F = –3.12; p = 0.002), and the proportion of restless sleep (χ^2 = 6. 16; p = 0.013) were significantly higher in the ADHD group than in the control group. The K-ARS, BASC-2, and ADS subscale scores indicated significantly poorer outcomes with respect to behavioral and cognitive functions in the ADHD group than those in the control group.

Comparison of the behavioral and cognitive functions between the high- and low-risk SDB groups within the ADHD group

The results of the comparison of the behavioral and cognitive functions between the high- and low-risk SDB subgroups in the ADHD group are shown in Table 2. The scores on the BASC-2 subscales of externalizing problems (F = 4.22; p = 0.042), including hyperactivity (F = 4.65; p = 0.033) and attention problems (F = 8.19; p = 0.005), differed significantly between the high- and low-risk SDB groups. However, internalizing problems, such as anxiety and depression, did not differ significantly between both groups. Furthermore, none of the ADS subscale scores differed significantly between the high- and low-risk SDB groups.

Comparison of the behavioral and cognitive functions between the high- and low-risk SDB groups within the control group

The results of the comparison of the behavioral and cognitive functions between the high- and low-risk SDB subgroups in the control group are shown in Table 3. Contrary to the

ADHD group, the control group had significant differences between the high- and low-risk SDB groups in terms of scores in internalizing problems ($F = 9.89$; $p = 0.002$), depression ($F = 9.45$; $p = 0.002$), and somatization ($F = 7.83$; $p = 0.006$), as well as in externalizing problems ($F = 7.72$; $p = 0.006$), including hyperactivity ($F = 6.23$; $p = 0.013$), aggression ($F = 5.00$; $p = 0.027$), and conduct problems ($F = 6.79$; $p = 0.010$). Finally, similar to the results of the ADHD group, the control group did not have significantly differences between the high- and low-risk SDB subgroups in terms of the ADS subscale scores.

Linear regression for the association between SDB scores and the behavioral and cognitive function scores

Table 4 shows the results of the linear regression analysis performed for identifying the association between SDB scores and the behavioral and cognitive functions scores in the ADHD and control groups.

In the control group, the SDB score showed a significantly positive association with the K-ARS total ($\beta = 0.144$; $p = 0.047$) and inattention subscale ($\beta = 0.182$; $p = 0.012$) scores. The SDB score also presented a significantly positive association with the externalizing ($\beta = 0.154$; $p = 0.035$) and internalizing ($\beta = 0.222$; $p = 0.002$) problems on the BASC-2 scale. In ADS, the SDB score had a significantly negative association with only the auditory commission error ($\beta = -0.153$; $p = 0.039$).

Contrarily, in the ADHD group, the SDB score did not show a significant association with the K-ARS scores. Furthermore, the SDB score had a significantly positive association with externalizing problems ($\beta = 0.231$; $p = 0.004$), but not with internalizing problems. The SDB score did not show significant associations with the scores on any subscales of ADS.

Discussion

The present cross-sectional study investigated the associations between SDB and behavioral and cognitive functions among elementary school children with ADHD and compared them with those identified in children without ADHD (controls). The findings of our study indicated that SDB was positively associated with multiple externalizing and internalizing problems in both children with and without ADHD. However, in a subgroup analysis, SDB was associated with higher BASC-2 subscale scores in control children than in children with ADHD.

The findings of the present study regarding the associations between SDB and various pediatric behavioral functions are interesting when compared with those of previous studies. For instance, several studies comparing behavioral problems between children with OSA and controls consistently reported significant associations between SDB and externalizing problems such as inattention, hyperactivity, and aggression, regardless of the ADHD diagnosis.[18,28] In a review of 20 studies evaluating the association of neurobehavioral morbidity with SDB, 12 studies reported positive associations between SDB and hyperactivity/impulsivity, whereas five studies reported mixed findings.[28] Moreover, among the 13 studies that investigated the associations between SDB and inattention, only two reported null findings, whereas seven and four studies reported positive and mixed findings, respectively.[28] Our finding of a positive association between SDB and externalizing problems in both the ADHD and control groups is consistent with these previous results.

Compared with the mainly consistent findings for externalizing problems, previous studies have reported relatively inconsistent findings on the association of SDB with the

internalizing behavioral problems. Only two studies found clear elevation of anxiety or depression in children with SDB on direct measurement, whereas two and eight studies found mixed or no significant associations, respectively.[28] Our study found a significant association between SDB and internalizing problems in the control group, but not in the ADHD group. These differences in the associations between SDB and internalizing problems suggest that, in certain individuals, moderating factors (such as an ADHD diagnosis) might be involved, which may have affected the results of the previous associative studies. Furthermore, the stronger association identified between SDB and externalizing problems in the control group than in the ADHD group suggests that the relationship between SDB and externalizing problems in children with ADHD may be masked by the effects of the ADHD psychopathology.

Contrary to the behavioral aspects, our study did not find significant differences in cognitive attention performance (assessed by the continuous performance test) between the high- and low-risk SDB groups in either the control or ADHD groups; in the linear regression analysis, only the auditory commission error in the control group had slightly significant association with the SDB score. These findings are interesting when compared with the inconsistent results of previous studies. Some studies have reported that OSA is associated with poor attention performance.[19,29,30] In a prospective study on 1,010 snoring and non-snoring children aged 5 to 7 years, the mild and severe OSA groups exhibited a more impaired visual attention performance, as assessed using NEPSY, a developmental neuropsychological test.[19] Another study on 28 children with and without OSA aged 4 to 8 years found that the OSA group was more impaired than the control group with respect to the visual attention performance on NEPSY.[20]

Contrarily, other studies have reported no significant associations between OSA and attention performance.[21,22,31-33] Similarly, a study on 153 children aged 3 to 5 years found no significant differences in visual attention performance, as assessed by NEPSY, among various groups categorized by SDB severity (control, PS, mild OSA, and moderate/severe OSA).[22] Giordani et al.[32] reported no significant differences in the sustained attention performance between the control and OSA groups in 79 children aged 5 to 12 years. Such inconsistencies have additionally been reported for various cognitive aspects regarded as separable domains, such as the IQ, memory, language, and academic achievement.[18]

Collectively, the findings of the present and previous studies suggest that the associations between SDB and impairments in the cognitive function are less prominent than the associations between SDB and unfavorable behavioral problems, especially externalizing problems. These discrepancies between the behavioral and cognitive aspects might be explained from different perspectives. Giordani et al.[32] suggested that a lack of association between SDB and cognitive function might reflect a combination of factors, including age, daytime sleepiness, features of SDB too minimal to be evident on standard polysomnography (PSG), and academic or environmental factors. The duration of SDB might be another variable for cognitive function impairment. Jackman et al.,[22] who studied a population of younger children (3–5 years), did not find a significant association between SDB and cognitive dysfunction, whereas a study on older school-aged children (7–12 years) did identify a significant association between these factors.[34] Such findings suggest that the cumulative effects of years of habitual snoring or OSA may be evident in the brains of older children, but they may not be apparent in younger children.

Behavioral adaptation in a child is determined by multiple genetic and environmental factors and their interactions.[35] ADHD is a multifactorial disorder influenced by environmental factors, with genetics playing a major role.[36] Our study suggests that the behavioral functions of children may be influenced by various factors such as SDB and ADHD diagnosis. Additionally, our findings suggest that routine activities of the participants, as observed by parents, can be more easily affected than cognitive functions. The ability to perform tasks requiring cognitive effort is relatively more preserved in children with SDB. To elucidate the biological mechanisms underlying the discrepancies between associations of SDB with cognitive and with behavioral functions, more sophisticated studies are needed in the future.

Our study has a few limitations. First, the SDB symptoms were assessed by parental ratings alone, and no objective measurements (such as PSG) were utilized. This might lower the sensitivity of SDB symptom detection. In fact, previous studies using PSG reported a higher prevalence of SDB in children with ADHD (50% and 56.8%)[11,12] than that observed in our study (16.1%), and this warrants future studies incorporating the PSG to confirm the present findings. Nevertheless, previously, chronic snoring in children was found to be more strongly associated with poor neurobehavioral outcomes than with PSG-defined OSA.[28] Chervin et al.[13] also reported that PSG assessments did not clearly predict baseline neurobehavioral morbidities. Thus, the parent-rated questionnaire could be a useful assessment tool for evaluating chronic snoring in children. Second, the internalizing and externalizing functions were assessed only by the parent-reported scale. This is a common shortcoming of most previous studies.[28] However, reports of psychiatric symptoms from children and parents are often discrepant.[37] Parents tend to report internalizing symptoms,

such as depression and anxiety, less seriously than children do, because these symptoms are less visible than the externalizing symptoms.[38] Thus, future studies that include information from multiple informants are needed to accurately evaluate the children's emotional functions. Third, the limited sample size is another shortcoming of our study. Additional studies with more participants will be helpful for confirming the associations between SDB and the behavioral and cognitive functions in children. Finally, although ADHD was diagnosed through a diagnostic interview by a trained psychiatrist on the basis of the DSM-IV-TR criteria,[39] a structured diagnostic tool to cover the full spectrum of psychiatric disorders was not adopted. Thus, other psychiatric disorders such as depression and anxiety were not considered in the process of diagnosis; this may introduce some bias in the selection of the control group.

Conclusions

The present study extends our understanding of the associations between SDB and the behavioral and cognitive functions in children with ADHD and how these differ among those in healthy controls. Although SDB was positively associated with internalizing and externalizing behavioral problems, it was not associated with cognitive functions in school-aged children. Additionally, our findings suggest that the association between SDB and behavioral problems may be mediated by other factors such as an ADHD diagnosis.

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Potential conflicts of interest

The authors have no conflicts of interest.

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Table 1. Characteristics of the participants

Variable		Control group	ADHD group	χ2 or t	p
Number of participants		186	155		
SDB risk, n (%)	Low	166 (89.2)	130 (83.9)	2.133	0.152
	High	20 (10.8)	25 (16.1)		
Age (mean, SD)		7.71 (0.95)	7.39 (0.84)	3.21	0.001**
Sex, n (%)	Male	117 (63.2%)	110 (71.0%)	2.27	0.132
	Female	68 (36.8%)	45 (29.0%)		
Paternal education level, n (%)	≤ 12 years	60 (32.3%)	74 (47.7%)	8.50	0.004**
	> 12 years	126 (67.7%)	81 (52.3%)		
Maternal education level, n (%)	≤ 12 years	86 (46.2%)	91 (58.7%)	5.27	0.022*
	> 12 years	100 (53.8%)	64 (41.3%)		
Household income, n (%) (1,000 KRW per month)	≤ 2,000	25 (13.4%)	30 (19.4%)	7.64	0.106
	2,000 to 3,000	43 (23.1%)	49 (31.6%)		
	3,000 to 4,000	60 (32.3%)	35 (22.6%)		
	4,000 to 5,000	34 (18.3%)	25 (16.1%)		
	> 5,000	24 (12.9%)	16 (10.3%)		
SDB score (mean, SD)		0.11 (0.15)	0.15 (0.20)	-2.10	0.036*
Daytime sleepiness (mean of 4 items)		0.14 (0.22)	0.21 (0.22)	-3.12	0.002**
Restless sleep, n(%)	No	100 (53.8%)	62 (40.3%)	6.16	0.013*
	Yes	86 (46.2%)	92 (59.7%)		
Restless leg symptom, n(%)	No	153 (82.3%)	121 (78.1%)	0.94	0.332
	Yes	33 (17.7%)	34 (21.9%)		
K-ARS (mean, SD)					
Total		6.55 (8.18)	22.85 (8.69)	-17.80	<0.001**
Hyperactivity-impulsivity		2.79 (3.96)	10.22 (4.59)	-16.06	<0.001**
Inattention		3.76 (4.57)	12.63 (5.04)	-17.03	<0.001**
BASC-2 (mean, SD)					
Externalizing problems		44.49 (7.49)	53.54 (9.59)	-9.56	<0.001**
Internalizing problems		42.63 (8.62)	47.24 (9.68)	-4.59	<0.001**
Behavioral symptom index		45.99 (8.42)	54.80 (9.37)	-9.12	<0.001**
Adaptive skills		47.71 (8.64)	41.19 (8.22)	7.09	<0.001**
ADS (mean, SD)					
Visual omission error		50.64 (12.71)	66.23 (27.02)	-6.60	<0.001**
Visual commission error		49.92 (10.82)	66.05 (24.74)	-7.53	<0.001**
Auditory omission error		46.23 (8.68)	56.83 (16.30)	-7.27	<0.001**
Auditory commission error		43.86 (7.94)	53.30 (15.20)	-6.97	<0.001**

SDB, sleep disordered breathing; ADHD, attention deficit/hyperactivity disorder; K-ARS, Korean version of the ADHD Rating Scale; BASC-2, Behavior Assessment System for Children, Second Edition; ADS, ADHD Diagnostic System; * p<0.05; ** p<0.01.

Table 2. Comparison of behavioral and cognitive functions between the SDB groups in children with ADHD

Variable	SDB group		Crude model		Adjusted model[1]	
	Low-risk (n=130)	High-risk (n=25)	F	p	F	p
K-ARS						
Total	22.65 (9.15)	23.88 (5.72)	0.42	0.520	0.35	0.553
Hyperactivity-impulsivity	10.14 (4.77)	10.64 (3.57)	0.25	0.618	0.17	0.678
Inattention	12.52 (5.28)	13.24 (3.6)	0.43	0.512	0.42	0.517
BASC-2						
Hyperactivity	54.65 (10.54)	58.96 (11.39)	3.41	0.067	4.65	0.033*
Aggression	51.22 (8.42)	53.28 (11.16)	1.13	0.290	1.85	0.176
Conduct problems	52.03 (10.1)	55.76 (9.43)	2.92	0.090	3.05	0.083
Anxiety	43.78 (8.4)	44.64 (10.18)	0.20	0.653	0.24	0.627
Depression	52.81 (10.31)	54.48 (9.01)	0.57	0.450	0.54	0.465
Somatization	45.75 (9.46)	49 (10.34)	2.39	0.124	2.92	0.090
Atypicality	52.5 (10.6)	56 (12.13)	2.18	0.142	2.26	0.135
Withdrawal	49.45 (9.04)	50.52 (7.67)	0.31	0.579	0.29	0.589
Attention problems	58.99 (8.69)	64.64 (8.09)	9.05	0.003**	8.19	0.005**
Adaptability	46.09 (8.92)	43.96 (8.55)	1.21	0.273	0.58	0.447
Social skills	41.05 (8.98)	38.88 (8.45)	1.24	0.267	0.87	0.353
Leadership	43.07 (8.56)	39.84 (8.28)	3.01	0.085	1.56	0.214
Activities of daily living	40.72 (8.82)	34.72 (9.38)	9.50	0.002**	7.51	0.007**
Functional communication	43.98 (9.99)	41.64 (10.28)	1.14	0.288	0.45	0.505
Externalizing problems	52.94 (9.4)	56.68 (10.16)	3.24	0.074	4.22	0.042*
Internalizing problems	46.88 (9.68)	49.08 (9.62)	1.08	0.300	1.25	0.265
Behavioral symptom index	54.17 (9.25)	58.08 (9.54)	3.71	0.056	4.15	0.044*
Adaptive skills	41.79 (8.01)	38.04 (8.76)	4.46	0.036*	2.81	0.096
ADS						
Visual omission error	67.26 (28.49)	60.88 (16.87)	1.17	0.281	1.43	0.234
Visual comission error	65.58 (23.85)	68.44 (29.37)	0.28	0.599	0.42	0.519
Visual response time	52.73 (14.47)	53.36 (15.39)	0.04	0.844	0.21	0.647
Visual response time variability	69.26 (24.47)	68.84 (29.18)	0.01	0.939	0.04	0.850
Auditory omission error	56.47 (16.56)	58.72 (15.06)	0.40	0.529	0.45	0.501
Auditory comission error	53.08 (15.46)	54.44 (14.05)	0.17	0.684	0.15	0.703
Auditory response time	59.92 (17.95)	57.8 (15.87)	0.30	0.582	0.21	0.646
Auditory response time variability	62.48 (15.13)	64.6 (13.68)	0.42	0.517	0.74	0.391

SDB: sleep disordered breathing; ADHD, attention-deficit/hyperactivity disorder; K-ARS: Korean version of the ADHD Rating Scale; BASC-2: Behavior Assessment System for Children, Second Edition; ADS: ADHD Diagnostic system;

[1] Adjusted model: sex, age, paternal and maternal education level, and household income level were included as covariates.

* $p<0.05$; ** $p<0.01$.

Table 3. Comparison of behavioral and cognitive functions between the SDB groups in controls

Variable	SDB group		Crude model		Adjusted model[1]	
	Low-risk (n=166)	High-risk (n=20)	F	p	F	p
K-ARS						
Total	6.37 (8.21)	8.10 (8.03)	0.80	0.373	1.18	0.278
Hyperactivity-impulsivity	2.77 (3.99)	2.95 (3.75)	0.04	0.849	0.17	0.680
Inattention	3.60 (4.53)	5.15 (4.72)	2.08	0.151	2.56	0.111
BASC-2						
Hyperactivity	44.44 (8.23)	49.30 (9.94)	5.94	0.016*	6.23	0.013*
Aggression	45.05 (6.45)	48.65 (10.23)	4.79	0.030*	5.00	0.027*
Conduct problems	44.23 (6.96)	48.35 (7.50)	6.15	0.014*	6.79	0.010*
Anxiety	42.15 (7.59)	45.15 (8.13)	2.74	0.099	3.41	0.067
Depression	45.84 (7.31)	51.30 (12.03)	8.45	0.004**	9.45	0.002**
Somatization	42.73 (7.50)	48.15 (14.31)	7.31	0.007**	7.83	0.006**
Atypicality	46.34 (7.75)	50.30 (8.45)	4.57	0.034*	4.89	0.028*
Withdrawal	48.18 (9.53)	52.25 (10.19)	3.20	0.075	3.03	0.083
Attention problems	48.73 (9.36)	52.85 (10.41)	3.36	0.068	2.78	0.097
Adaptability	50.32 (9.11)	46.15 (10.38)	3.63	0.058	3.10	0.080
Social skills	44.62 (8.64)	43.05 (7.35)	0.61	0.436	0.55	0.460
Leadership	46.42 (9.02)	42.30 (7.45)	3.84	0.051	3.74	0.055
Activities of daily living	50.42 (9.28)	42.25 (10.11)	13.58	<0.001**	14.77	<0.001**
Functional communication	50.83 (9.32)	45.65 (10.41)	5.37	0.022*	5.97	0.016*
Externalizing problems	43.98 (7.10)	48.65 (9.37)	7.16	0.008**	7.72	0.006**
Internalizing problems	41.99 (7.69)	47.90 (13.31)	8.72	0.004**	9.89	0.002**
Behavioral symptom index	45.39 (8.08)	50.95 (9.74)	8.08	0.005**	8.25	0.005**
Adaptive skills	48.29 (8.52)	42.90 (8.28)	7.18	0.008**	7.29	0.008**
ADS						
Visual omission error	50.85 (13.07)	48.95 (9.29)	0.40	0.530	0.53	0.468
Visual comission error	50.04 (11.05)	49.00 (8.86)	0.16	0.687	0.00	0.957
Visual response time	48.57 (10.19)	50.15 (10.71)	0.42	0.517	0.29	0.593
Visual response time variability	50.02 (8.74)	51.05 (8.08)	0.25	0.616	0.26	0.610
Auditory omission error	46.13 (8.89)	47.10 (6.84)	0.22	0.638	0.03	0.860
Auditory comission error	43.99 (8.29)	42.80 (3.98)	0.40	0.527	0.68	0.411
Auditory response time	57.38 (13.34)	60.00 (12.59)	0.69	0.406	0.40	0.529
Auditory response time variability	50.91 (11.62)	54.50 (12.37)	1.67	0.197	1.19	0.276

SDB: sleep disordered breathing; K-ARS: Korean version of the ADHD Rating Scale; ADHD, attention deficit/hyperactivity disorder; BASC-2: Behavior Assessment System for Children, Second Edition; ADS: ADHD Diagnostic System;

[1] Adjusted model: sex, age, paternal and maternal education level, and household income level were included as covariates.

* $p<0.05$; ** $p<0.01$.

Table 4. Linear regression for the associations between SDB score and the behavioral and cognitive function

	Crude model			Adjusted model[1]		
	B	β	p	B	β	p
Control group (n = 186)						
K-ARS						
Total	9.86 (1.89 to 17.84)	0.177	0.016*	7.96 (0.11 to 15.81)	0.144	0.047*
Hyperactivity-Impulsivity	3.16 (-0.73 to 7.05)	0.117	0.111	2.35 (-1.5 to 6.19)	0.088	0.230
Inattention	6.71 (2.29 to 11.12)	0.216	0.003**	5.61 (1.27 to 9.96)	0.182	0.012*
BASC-2						
Externalizing problems	8.74 (1.43 to 16.05)	0.172	0.019*	7.83 (0.54 to 15.12)	0.154	0.035*
Internalizing problems	14.64 (6.37 to 22.91)	0.250	0.001**	13.00 (4.73 to 21.27)	0.222	0.002**
Behavioral symptom index	11.97 (3.81 to 20.13)	0.209	0.004**	10.59 (2.52 to 18.66)	0.185	0.010*
Adaptive skills	-11.24 (-19.64 to -2.85)	-0.192	0.009**	-9.7 (-18.11 to -1.30)	-0.165	0.024*
ADS						
Visual omission error	-4.07 (-16.67 to 8.53)	-0.047	0.525	-3.70 (-16.50 to 9.11)	-0.043	0.570
Visual commission error	-2.39 (-13.12 to 8.35)	-0.033	0.661	-2.56 (-13.02 to 7.89)	-0.035	0.629
Auditory omission error	-2.24 (-10.85 to 6.38)	-0.038	0.609	-1.42 (-9.50 to 6.65)	-0.024	0.728
Auditory commission error	-8.79 (-16.57 to -1.02)	-0.163	0.027*	-8.26 (-16.09 to -0.42)	-0.153	0.039*
ADHD group (n = 155)						
K-ARS						
Total	5.1 (-1.76 to 11.95)	0.118	0.144	4.71 (-2.19 to 11.6)	0.109	0.180
Hyperactivity-Impulsivity	2.59 (-1.04 to 6.21)	0.113	0.160	2.34 (-1.35 to 6.03)	0.103	0.211
Inattention	2.51 (-1.47 to 6.5)	0.100	0.215	2.36 (-1.61 to 6.33)	0.094	0.241
BASC-2						
Externalizing problems	10.43 (2.99 to 17.86)	0.219	0.006**	11.04 (3.52 to 18.56)	0.231	0.004**
Internalizing problems	6.04 (-1.6 to 13.67)	0.126	0.120	6.37 (-1.45 to 14.19)	0.133	0.109
Behavioral symptom index	10.49 (3.24 to 17.75)	0.225	0.005**	10.58 (3.18 to 17.98)	0.227	0.005**
Adaptive skills	-7.98 (-14.39 to -1.57)	-0.195	0.015*	-7.02 (-13.49 to -0.55)	-0.172	0.034*
ADS						
Visual omission error	-14.48 (-35.82 to 6.86)	-0.108	0.182	-15.45 (-37.38 to 6.47)	-0.115	0.166
Visual commission error	7.38 (-12.24 to 27)	0.060	0.458	10.37 (-9.11 to 29.84)	0.084	0.295
Auditory omission error	3.08 (-9.86 to 16.03)	0.038	0.638	4.25 (-8.79 to 17.3)	0.052	0.520
Auditory commission error	2.31 (-9.76 to 14.38)	0.031	0.706	2.53 (-9.82 to 14.88)	0.033	0.686

ADHD, Attention-Deficit/Hyperactivity Disorder; SDB, Sleep Disordered Breathing; K-ARS, Korean version of the ADHD Rating Scale; BASC-2, Behavior Assessment System for Children, Second Edition; ADS, ADHD Diagnostic system;

[1] Adjusted model: Sex, age, paternal and maternal educational level, and household income level were included as covariates.

* p<0.05; ** p<0.01

Highlights

- The link of SDB with behavioral and cognitive functions in children was investigated.
- Children with ADHD were compared with controls and grouped according to SDB risk.
- SDB was associated with externalizing behavioral problems in the ADHD group.
- The control group showed significant associations between SDB and internalizing and externalizing behavioral problems.
- Cognitive functions were not significantly associated with SDB in the control or ADHD group.

Potential conflicts of interest

The authors have no conflicts of interest.