SLEEP-DISORDERED BREATHING SYMPTOMS ARE ASSOCIATED WITH POORER COGNITIVE FUNCTION IN 5-YEAR-OLD CHILDREN

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Objective To assess the relation of sleep-disordered breathing (SDB) symptoms in children to neurocognitive function.

Study design A cross-sectional, population-based study of 205 5-year-old children. A parent-completed questionnaire was used to ascertain SDB symptoms, defined as frequent snoring, loud or noisy breathing during sleep, or witnessed sleep apnea. Polysomnography (PSG) data were available in 85% of children. Standardized neurocognitive tests were administered by a trained psychometrist unaware of the children's SDB status. Children with (n = 61) and without SDB symptoms were compared using analysis of variance to adjust for demographic and respiratory health variables.

Results Children with SDB symptoms scored significantly lower than those without SDB symptoms on tests of executive function (95.5 vs 99.9 on NEPSY Attention/Executive Core Domain, $P = .02$; 10.4 vs 11.2 on Wechsler Preschool and Primary Scale of Intelligence, Revised [WPPSI-R] Animal Pegs test, $P = .03$), memory (96.8 vs 103.0 on NEPSY Memory Domain, $P = .02$), and general intellectual ability (105.9 vs 111.7 on WPPSI-R Full Scale IQ, $P = .02$). There were no significant differences on a computerized continuous performance task. These findings persisted when children with PSG evidence of obstructive sleep apnea (OSA) were excluded from analysis.

Conclusion Even in the absence of OSA, SDB symptoms are associated with poorer executive function and memory skills and lower general intelligence in 5-year-old children. *(J Pediatr 2004;145:458-64)*

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Sleep-disordered breathing (SDB) is increasingly recognized in young children, with obstructive sleep apnea (OSA) estimated to affect 1% to 3% of preschool-age children and habitual snoring estimated to affect 10% or more of preschool-age children.[1-5] These figures likely underestimate the magnitude of the problem, as many parents who do not report habitual snoring nonetheless report that their children have loud, noisy breathing during sleep, a symptom associated with behavior problems similar to those of habitual snoring.[6] Although children with SDB may experience daytime sleepiness, they also exhibit problems of behavioral regulation suggestive of the attention deficit-hyperactivity disorder (ADHD).[1,6,7-10] These behavioral problems suggest that childhood SDB might impair frontal lobe-mediated executive function,[11] which develops throughout childhood.[12] An association of SDB symptoms in children with poor academic performance[13,14] and parent-reported learning problems[15] has been reported, and PSG evidence of SDB was recently shown to be associated with parent-reported learning problems in 6- to 11-year-old children.[16] Adenotonsillectomy has been associated with improved school performance in poorly performing first grade children with OSA[14]; however, early childhood snoring has been associated with poor academic performance in

ADHD	Attention deficit-hyperactivity disorder	OAI	Obstructive Apnea Index
AHI	Apnea-Hypopnea Index	OSA	Obstructive sleep apnea
CPRS	Conners' Parent Rating Scale, Long Form	PSG	Polysomnography
CPT	Continuous performance task	PSQ	Pediatric Sleep Questionnaire
FYFQ	Five-year follow-up questionnaire	SDB	Sleep-disordered breathing
ICPS	Infant Care Practices Study	WPPSI-R	Wechsler Preschool and Primary Scale of Intelligence, Revised
MANOVA	Multivariate analysis of variance		

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middle school,[17] suggesting the possibility of permanent impairment or a long-term "learning debt" beginning in the preschool or early school years.

Notwithstanding anecdotal reports and uncontrolled case series, there are few published studies using standardized measures to assess the neurocognitive effects of SDB in children. One study found impaired attention on an auditory continuous performance task (CPT) in 16 children 5 to 10 years of age with primary snoring or mild OSA when compared with 16 nonsnoring controls.[18] In contrast, a study of similar size found no significant differences in CPT performance between children with OSA, primary snoring, or no snoring who were referred for adenotonsillectomy.[19] This study did find, however, a significantly greater postoperative improvement in CPT number correct, but not commission errors, in the OSA children compared with the nonsnoring controls.[19] Two studies have reported significantly impaired memory in children with snoring or OSA,[18,20] whereas there have been conflicting reports on the relation of OSA to IQ.[18-20] Interpretation of and generalization from these studies is limited by small sample sizes, clinically referred patient samples, and a limited range of neurocognitive tests. The present study overcomes these limitations by examining the association of SDB symptoms with performance on standardized measures of executive function, memory, and intellectual ability in a large, population-based sample of 5-year-old children, an age that is particularly important for the development of executive function.

METHODS

Subjects

This study was approved by the Institutional Review Boards of Boston University School of Medicine and Rush University. All children had been previously enrolled in the Infant Care Practices Study (ICPS).[21] Briefly, the ICPS is a multicenter, prospective longitudinal study conducted in Massachusetts and Ohio, the principal aim of which was to describe newborn sleep practices and to document changes in infant sleep position over time. Between February 1995 and December 1998, mothers of newborn infants were contacted at selected birth hospitals and invited to participate. Beginning in March 2000, a Five-Year Follow-up Questionnaire (FYFQ) was mailed within 2 months of the child's fifth birthday to all English-speaking mothers of children in the ICPS born in Massachusetts with birth weight >2500 g. [6] An invitation letter with reply postcard was sent to all mothers who indicated on the FYFQ that they were willing to be contacted regarding additional studies. All those who returned a postcard indicating that they were interested in participating or wanted more information were contacted by telephone. Those not returning a postcard were put in a telephone queue for follow-up, which was terminated after 10 unsuccessful attempts . All contacted parents were invited to participate in the study, and written informed consent was obtained from the parent of each enrolled child. The subjects of this study are all children with complete FYFQ data on sleep symptoms who also completed the laboratory-based neurocognitive assessment. Overnight PSG was scheduled for all participants and was completed by 88%. Subjects with Full Scale IQ <70 were excluded from analysis a priori, as the results of neurocognitive testing were believed to be unreliable in the presence of this degree of intellectual impairment.

Parent Report Data

Descriptive data, including maternal race, ethnicity, and educational status were collected by interview at the time of enrollment into the ICPS. The FYFQ asked the child's height, weight, frequency of upper respiratory and ear infections, history of tympanostomy and adenotonsillectomy, daytime sleepiness, wheezing, asthma, respiratory allergy, and the following questions regarding SDB symptoms: "On average, how often does your child snore?" (response options: never, <1, 1-2, 3-5, or 6-7 nights per week), "Have you ever seen your child stop breathing when he/she was asleep?" (no or yes), and "When sleeping, does your child have 'heavy,' loud, or noisy breathing?" (no, yes, or don't know). The presence of SDB symptoms was defined as parent report of at least one of the following: snoring ≥3 nights per week; 'heavy,' loud, or noisy breathing during sleep; or witnessed nocturnal apneas. The Conners' Parent Rating Scale-Long Form (CPRS)[22] was completed by the parent on the day of the neurocognitive assessment. The Pediatric Sleep Questionnaire[23] (PSQ) was completed by the parent within several weeks of completion of neurocognitive testing.

Neurocognitive Assessment

The children were assessed individually by a trained psychometrist under the supervision of a pediatric neuropsychologist. The tester was unaware of the children's SDB symptom status. The assessment was conducted in one 3- to 4-hour session with breaks for a snack, play, lunch, and a brief physical examination by a study nurse. The neurocognitive assessment was composed of measures of attention, planning, memory, and general cognitive ability. The NEPSY Attention and Executive Core Domain (Tower, Auditory Attention, Visual Attention) and the NEPSY Memory Core Domain (Memory for Faces, Memory for Names, and Narrative Memory) were administered.[24] A 12-minute visual CPT called Catch the Cat, designed as a measure of sustained attention for preschoolers, was also administered.[25] The child then completed the Wechsler Preschool and Primary Scale of Intelligence, Revised (WPPSI-R)[26] including the Animal Pegs test.

Polysomnography

All children were invited to undergo overnight PSG approximately 2 weeks after neurocognitive testing. PSG was performed and scored in the General Clinical Research Center at Boston University School of Medicine by a registered PSG technician experienced in the performance of sleep studies in children, who was unaware of the results of neurocognitive

testing. The montage included electroencephalography, electro-oculography, submental electromyography, thoracic and abdominal excursions by inductive plethysmography, nasal-oral thermistry, end-tidal capnography, finger pulse oximetry and pulse waveform, electrocardiography, and leg electromyography. PSG findings were digitally recorded on a Compumedics PS-Quest system (Compumedics, Abbottsford, Australia). Sleep stages were scored according to the guidelines developed by Rechtschaffen and Kales.[27] Obstructive respiratory events were scored independent of the presence of associated oxyhemoglobin desaturation or electroencephalographic evidence of arousal. Obstructive apnea was defined as a complete cessation of airflow by thermistry and capnography lasting for at least one breath and accompanied by continued respiratory effort in the inductance bands. Obstructive hypopnea was defined as a reduction to ≤50% of the immediately preceding baseline amplitude in the thermocouple or respiratory band signals, lasting for at least two breaths and associated with a change in thoraco-abdominal synchrony on the inductance bands that was clearly discernible by visual inspection (phase angle was not measured). The Obstructive Apnea Index (OAI) was obtained by dividing the number of apneas by the number of hours of sleep, and the Apnea-Hypopnea Index (AHI) was obtained by dividing the total number of obstructive apneas plus hypopneas by the number of hours of sleep.

Analysis

All analyses were performed using Statistical Package for the Social Sciences software (SPSS, Inc, Chicago, Ill). The relation of SDB symptoms to measures of behavior (CPRS indices), attention and planning (NEPSY Attention/Executive Domain Index, Animal Pegs scaled score, and number of omission and commission errors on CPT), memory (NEPSY Memory Domain Index), and general intellectual ability (WPPSI-R Full Scale IQ) was examined using analysis of variance procedures. Multivariate models were used to adjust for potential confounders including sociodemographic variables (maternal race/ethnicity, marital status, and household income) and respiratory illness history (frequency of upper respiratory and ear infections, tympanostomy tube placement, and diagnosis of asthma or respiratory allergy). As multiple correlated neurocognitive outcome measures were employed, adjustment for multiple comparisons was performed using a multivariate analysis of variance (MANOVA) model that included all neurocognitive test measures as dependent variables in a single model. In order to determine whether the results were driven by the subset of children with overt OSA, these models were repeated in the subset of children with valid PSG data and an AHI ≥4 (the sample 95th percentile for AHI).

RESULTS

Between March 1, 2000 and May 3, 2002, 5-year follow-up was initiated approximately 2 months before the child's fifth birthday for 5811 children enrolled in the ICPS.

Table I. Demographic characteristics of the study sample and source cohort*

	Source cohort (n = 5811)	Screened (n = 3533)	Included (n = 205)
Child's sex			
Male	51.0	51.5	51.7
Female	49.0	48.5	48.3
Mother's race			
White non-Hispanic	69.7	81.2	82.0
Black non-Hispanic	10.6	6.3	7.8
Hispanic	11.7	6.5	7.8
Asian	6.6	4.9	1.5
Other or unknown	1.5	1.1	1.0
Marital status			
Never married	25.8	15.4	16.1
Married	71.6	83.0	81.5
Separated/Divorced/Widowed	2.3	1.4	1.5
Unknown	0.2	0.3	1.0
Mother's education			
<High school graduate	11.2	5.2	2.9
High school graduate	22.5	18.5	8.8
Some college	22.4	22.2	24.9
College graduate	43.6	53.9	62.4
Unknown	0.3	0.3	1.0
Household annual income			
<$16,000	11.9	7.1	7.3
$16,000–34,999	14.0	12.0	11.2
$35,000–54,999	17.3	19.0	11.2
≥$55,000	41.3	52.3	64.4
Unknown	15.6	9.7	5.9

*All values are percent.

At the time of this analysis, 3533 questionnaires (61%) had been completed and 219 children had been seen for neurocognitive assessment. Two children with low IQ scores, 5 who were unable to complete the assessment because of extreme shyness or anxiety, and 7 with incomplete data on SDB status were excluded. The remaining 205 children are the subjects of this study. There were approximately equal numbers of boys and girls. Compared with the total eligible sample, mothers of these children were more likely to be non-Hispanic white, married, better educated and to have higher household income (Table I). PSG was scheduled for all participants and was completed in 180 (88%), of whom 5 were excluded for a positive response to the question, "Does your child have a cold or respiratory infection?"

Parent-reported habitual snoring and other symptoms of SDB were quite common (Table II). Although snoring frequency was significantly associated with each of the other SDB symptoms, many children who were not reported to snore habitually were reported to have other symptoms of SDB. For example, of the 23% of children reported to have

Table II. Parental report of SDB symptoms*

	Screened (n = 3533)	Included (n = 205)
Snoring ≥3 nights per week	12.1	16.1
Loud or noisy breathing when asleep	16.6	22.9
Witnessed nocturnal apnea	3.3	6.3
Any SDB symptom†	24.2	29.8

*All values are percent.
†SDB defined as parent-reported habitual (≥3 nights per week) snoring, loud or noisy breathing when asleep, or witnessed sleep apnea.

loud or noisy breathing during sleep, more than half were not reported to be habitual snorers. As habitual snoring, loud or noisy breathing, and witnessed apneas are each predictive of the presence of PSG abnormalities,[23] a composite SDB variable indicating the presence of any of the three SDB symptoms was used to categorize the study subjects. Using this definition, parent-reported SDB symptoms were present in 30% of participants, with a trend toward higher prevalence in participants than in the entire screened sample (P = .056). The prevalence of SDB symptoms was similar in boys and girls (32% vs 27%, P = .45). The children with SDB symptoms had a significantly higher mean score (0.30 ± 0.19 vs 0.14 ± 0.13, P < .001) on the PSQ, a validated tool for identification of children with PSG evidence of OSA or obstructive hypoventilation.[23]

Based on parental responses to the CPRS, children with SDB symptoms were significantly more symptomatic on the ADHD Index and Cognitive/Inattention scales than were children without SDB symptoms, after adjustment for demographic and respiratory health variables (Table III). There was no significant difference on the Hyperactivity scale. Children with SDB symptoms did not perform as well on standardized measures of attention and planning as did children without SDB. Children with SDB symptoms had significantly lower NEPSY Attention/ Executive Domain Index scores (Table III). This index is a summary of age-based scores on three subtests: Visual Attention, Auditory Attention, and Tower. The former two are measures of attention, whereas Tower evaluates planning. Secondary analysis revealed a trend toward lower scores on each of the three subtests among children with SDB symptoms. Children with SDB symptoms also performed significantly more poorly on the Animal Pegs test of the WPPSI-R, a test of attention, planning, and efficiency (Table III). In this timed test, there were few errors made by any of the children, and the difference reflects a more rapid completion of the task by children without SDB symptoms. Although the Tower component of the NEPSY Attention/Executive Domain is an untimed planning task, the trend toward poorer performance by children with SDB symptoms was of similar magnitude (10.2 ± 0.3 vs 10.9 ± 0.2). On the computerized CPT, another measure of sustained attention, children with SDB symptoms committed 30% more errors of commission than did children without SDB symptoms, although given the high variance of the measure this trend was not statistically significant (Table III). Children with SDB symptoms also had a trend toward fewer correct responses on the CPT.

Children with SDB symptoms had significantly poorer performance than did those without SDB symptoms on the NEPSY Memory Domain Index (Table III). This index comprises both visual (Memory for Faces) and verbal (Narrative Memory) memory measures, with Memory for Names having both visual and verbal components. Each subtest measures immediate recall, whereas Memory for Names and Memory for Faces also test delayed recall. There was little difference between groups on the Memory for Faces measure, which almost all children performed without difficulty. In contrast, the children with SDB symptoms performed significantly less well on both subtests with a verbal memory component (7.9 ± 0.4 vs 9.3 ± 0.3 on Memory for Names; 9.9 ± 0.4 vs 11.0 ± 0.2 on Narrative Memory). SDB symptoms were also associated with significantly lower overall intellectual ability, with a WPPSI-R Full Scale IQ almost 6 points lower in children with SDB symptoms compared with those without SDB symptoms (Table III). The children with SDB symptoms performed less well on both the Performance Scale IQ (103.1 ± 2.0 vs 108.5 ± 1.2) and the Verbal Scale IQ (107.6 ± 1.9 vs 111.8 ± 1.2), although the difference was statistically significant only for the former. The largest difference between groups was observed in the Object Assembly subtest of the Performance Scale IQ, although the children with SDB symptoms had a trend toward lower scores on each of the eight WPPSI-R subtests.

There were no consistent differences between boys and girls in the association of SDB symptoms with either neurocognitive or behavior measures. Although the direction of effect was toward poorer performance among children with SDB symptoms on all measures, a formal test of significant differences across groups was performed using a MANOVA model in which all nine of the primary outcome measures (Table III) were included as dependent variables in a single model. The difference between children with and without SDB symptoms across all tests was significant at P = .01 by Wilks' Multivariate Test of Significance. When the CPRS scales were excluded, and only the six administered neurocognitive tests included in the model, the difference remained significant (P < .03).

In the absence of widely accepted normative data for AHI in children, we considered AHI ≥4 (the 95th percentile within this sample) to have PSG evidence of OSA. Both of the subjects with OAI ≥1 had AHI ≥4. Of 175 children with valid PSG data, 6 of 54 (11.1%) with SDB symptoms and 2 of 121 (1.7%) without SDB symptoms had PSG evidence of OSA (P < .01). Among the 167 subjects without OSA, the association of SDB symptoms with measures of behavioral regulation, executive function, memory, and general intelligence were similar in magnitude to those seen in the entire sample (Table III). The differences across groups remained

Table III. Association of SDB symptoms with executive function, memory, and general intellectual ability*

	Entire sample†			Subjects without OSA‡		
	SDB absent (n = 144)	SDB present (n = 61)	*P*	SDB absent (n = 119)	SDB present (n = 48)	*P*
Behavioral regulation						
CPRS ADHD Index	48.5 ± 0.8	53.6 ± 1.2	.001	48.6 ± 0.9	53.6 ± 1.4	.004
CPRS cognitive/inattention	49.4 ± 0.7	53.9 ± 1.1	.001	49.3 ± 0.7	53.3 ± 1.2	.009
CPRS hyperactivity	50.3 ± 0.7	52.9 ± 1.2	.07	50.4 ± 0.8	53.2 ± 1.4	.10
Attention and planning						
NEPSY Attention/Executive Domain Index	99.9 ± 1.0	95.5 ± 1.5	.02	99.7 ± 1.0	94.9 ± 1.6	.02
WPPSI-R Animal Pegs	11.2 ± 0.2	10.4 ± 0.3	.03	11.0 ± 0.2	10.3 ± 0.4	.08
Continuous performance task						
CPT number correct	33.3 ± 0.6	31.5 ± 0.9	.10	33.4 ± 0.6	31.6 ± 1.0	.12
CPT number of commission errors	24.2 ± 2.9	31.4 ± 4.6	.23	24.7 ± 3.2	33.7 ± 5.3	.17
Memory						
NEPSY Memory Domain Index	103.0 ± 1.3	96.8 ± 2.0	.02	102.5 ± 1.4	95.4 ± 2.3	.02
General intellectual ability						
WPPSI-R Full Scale IQ	111.7 ± 1.2	105.9 ± 1.9	.02	111.1 ± 1.3	105.2 ± 2.2	.03

*All values are adjusted mean ± SE, adjusted by analysis of variance for maternal race, marital status, and household income and child's frequency of upper respiratory and ear infections, tympanostomy tube placement, diagnosis of asthma, and respiratory allergies.
†Because of missing values in the total sample, the number of subjects is 200 for the CPT, 203 for NEPSY indices, and 204 for CPRS scales and the Animal Pegs test.
‡Subjects with PSG evidence of OSA (see text, n = 8) were excluded, as were subjects without valid PSG data (n = 30). Because of missing values in the sample without OSA, the number of subjects is 165 for the CPT and 166 for the NEPSY Memory Domain Index, CPRS scales, and the Animal Pegs test.

statistically significant in MANOVA models incorporating the full neurocognitive test battery ($P \leq .05$ by Wilks' Multivariate Test of Significance, with or without inclusion of the CPRS scales). The association between PSG evidence of OSA and neurobehavioral outcomes was not assessed because the number of subjects with PSG evidence of OSA was too small to have statistical power.

DISCUSSION

The present study finds that in a community sample of 5-year-old children, parent-reported symptoms of SDB are associated with impaired behavioral control and with significantly poorer performance on a broad range of neurocognitive tests, including standardized, age-appropriate tests of executive function, memory, and general intellectual ability, after adjustment for potentially confounding sociodemographic and respiratory health variables. Although not statistically significant for the CPT, the direction of effect was toward poorer performance in each neurocognitive measure, as well as in each of their subtests. The association of SDB symptoms with poorer neurocognitive function persists after exclusion of children with overt PSG evidence of OSA.

These data are consistent with a widespread impact of SDB on neurocognitive function, although impaired executive function may adversely affect performance on tests of other neurocognitive domains and the ability to reliably discriminate these in young children is uncertain. The results of this study are particularly striking in that the effects are observed in children with parent-reported symptoms of SDB drawn from a community-based sample, rather than children referred to a sleep laboratory. The neurocognitive effects of SDB are commonly attributed to either hypoxemia or sleep fragmentation, although in the present study the observed effects were not driven by the minority of children with PSG-identified OSA. Children with OSA have a greater degree of upper airway collapsibility than do those with primary snoring[28]; however, primary snoring is associated with increased upper airway resistance during sleep and may have neurobehavioral consequences. In adults, for example, snoring has been associated with sleepiness independent of the presence of OSA.[29,30]

Even among children with SDB symptoms, mean IQ scores in this study were above average, likely reflecting the high education and income level of the parents consenting to participate. Nonetheless, the magnitude of the difference between groups is potentially important given the high prevalence of SDB symptoms. For example, the mean difference in scores on the NEPSY Attention/ Executive Core Domain between children with and without SDB symptoms was approximately half as great as the reported difference between children with clinically diagnosed ADHD and healthy control children.[24] The observed difference in Full Scale IQ associated with SDB symptoms is greater than that associated with an increase in blood lead levels from 10 to 30 mcg/dL in children living near lead smelters[31,32] and more than twice that associated with more modest childhood lead exposure.[33]

Compared with prior studies of subjects derived from clinical populations, the present study has the advantage of drawing subjects from a defined, population-based cohort rather than from clinical referrals, with consequent reduction in the likelihood of referral bias. The neurocognitive test battery included a wide range of standardized and age-appropriate measures administered in blinded fashion by trained psychometrists under the direction of a clinical neuropsychologist with extensive experience in assessment of young children. Only 6% of questionnaire-screened children were ultimately enrolled in the study and, as in any observational study, the possibility of confounding by unmeasured variables cannot be excluded, although the availability of detailed covariate data allowed adjustment for sociodemographic and respiratory health variables expected a priori to be associated with both SDB risk and neurocognitive performance. As shown in Table I, the study sample derives from households with higher income and maternal educational level than does the population-based source cohort and includes fewer minority children, which may limit the generalizability of the results. Although there are at present no data suggesting racial or ethnic differences in the neurocognitive effects of SDB, the present study has insufficient power to exclude such differences.

The study also relies on parent report of SDB symptoms as the exposure of interest. The parent report measure was validated, however, against both the PSQ and PSG. In the validation sample, 43% of children with SDB symptoms, versus 9% of children without SDB symptoms, had scores >0.33 on the PSQ, the threshold reported to best discriminate children with from those without PSG evidence of OSA.[23] Although both habitual snoring and witnessed apneas are widely accepted as markers of OSA, "heavy or loud breathing" had the largest odds ratio of any single item on the PSQ as a predictor of OSA,[23] and is therefore appropriately included in our SDB symptom measure. Moreover, the presence of SDB symptoms as defined in this study was a strong predictor of overt polysomnographic OSA.

The restriction to a narrow age range is both a strength and a weakness of the present study. As the manifestations of SDB vary by age, restricting the age range removes a potential source of variance, thereby increasing the likelihood of detecting significant SDB effects but limiting their generalizability to other ages. The natural history of SDB in children has received little study. Although one study reported that snoring prevalence did not change between the ages of 4 and 7 years, only 50% of children who snored habitually at baseline continued to do so after 2 years.[34] The ages of 3 to 6 years are particularly important to the development of some aspects of executive function[35,36] and for acquisition of learning skills. It has been reported that children with poor academic performance at 13 to 14 years of age were more likely than were children with high academic performance to report early childhood snoring, although current snoring at 13 to 14 years of age was not significantly associated with performance.[17] The possible persistence of neurocognitive effects of early childhood SDB into later childhood and their impact on academic performance require further investigation.

REFERENCES

1. Ali NJ, Pitson DJ, Stradling JR. Snoring, sleep disturbance, and behaviour in 4-5 year olds. Arch Dis Child 1993;68:360-6.

2. Gislason T, Benediktsdottir B. Snoring, apneic episodes, and nocturnal hypoxemia among children 6 months to 6 years old. Chest 1995;107:963-6.

3. Hulcrantz E, Lofstrand-Tidestrom B, Ahlquist-Rastad J. The epidemiology of sleep related breathing disorder in children. Int J Pediatr Otorhi 1995;32:63S-6S.

4. Teculescu D, Caillier I, Perrin P, Rebstock E, Rauch A. Snoring in French preschool children. Pediatr Pulmonol 1992;13:239-44.

5. Castronovo V, Zucconi M, Nosetti L, Ossola E, Moscatelli D, Calori G, et al. Habitual snoring among children aged 3 to 6 years: an epidemiologic study with objective measurement of snoring and oxygen saturation. Sleep 1998;21:S51.

6. Gottlieb DJ, Vezina RM, Chase C, Lesko SM, Heeren TC, Weese-Mayer DE, et al. Sleep-disordered breathing in five-year-old children is associated with sleepiness and problem behaviors. Pediatrics 2003;112:870-7.

7. Guilleminault C, Korobkin R, Winkle R. A review of 50 children with obstructive sleep apnea syndrome. Lung 1981;159:275-87.

8. Frank Y, Kravath RE, Pollak CP, Weitzman ED. Obstructive sleep apnea and its therapy: clinical and polysomnographic manifestations. Pediatrics 1983;71:737-42.

9. Brouillette R, Hanson D, David R, Klemka L, Szatkowski A, Fernbach S, et al. A diagnostic approach to suspected obstructive sleep apnea in children. J Pediatr 1984;105:10-4.

10. Chervin RD, Archbold KH, Dillon JE, Panahi P, Pituch KJ, Dahl RE, et al. Inattention, hyperactivity, and symptoms of sleep-disordered breathing. Pediatrics 2002;109:449-56.

11. Beebe DW, Gozal D. Obstructive sleep apnea and the prefrontal cortex: towards a comprehensive model linking nocturnal upper airway obstruction to daytime cognitive and behavioral deficits. J Sleep Res 2002;11:1-16.

12. Welsh MC, Pennington BF. Assessing frontal lobe functioning in children: views from developmental psychology. Dev Neuropsychol 1988;4:199-230.

13. Weissbluth M, Davis AT, Poncher J, Reiff J. Signs of airway obstruction during sleep and behavioral, developmental, and academic problems. J Devel Behav Pediatr 1983;4:119-21.

14. Gozal D. Sleep disordered breathing and school performance in children. Pediatrics 1998;102:616-20.

15. Goodwin JL, Babar SI, Kaemingk KL, Rosen GM, Morgan WJ, Sherrill DL, et al. Symptoms related to sleep-disordered breathing in White and Hispanic children: the Tucson Children's Assessment of Sleep Apnea Study. Chest 2003;124:196-203.

16. Goodwin JL, Kaemingk KL, Fregosi RF, Rosen GM, Morgan WJ, Sherrill DL, et al. Clinical outcomes associated with sleep-disordered breathing in Caucasian and Hispanic children: the Tucson Children's Assessment of Sleep Apnea Study (TuCASA). Sleep 2003;26:587-91.

17. Gozal D, Pope DW. Snoring during early childhood and academic performance at ages thirteen to fourteen years. Pediatrics 2001;107:1394-9.

18. Blunden SL, Lushington K, Kennedy D, Martin J, Dawson D. Behavior and neurocognitive function in children aged 5-10 years who snore compared to controls. J Clin Exp Neuropsychol 2000;22:554-68.

19. Ali NJ, Pitson D, Stadling JR. Sleep disordered breathing: effects of adenotonsillectomy on behaviour and psychological functioning. Eur J Pediatr 1996;155:56-62.

20. Rhodes SK, Shimoda KC, Wald LR, O'Neil PM, Oexmann MJ, Collop NA, et al. Neurocognitive deficits in morbidly obese children with obstructive sleep apnea. J Pediatr 1995;127:741-4.

21. Lesko SM, Corwin MJ, Vezina RM, Hunt CE, Mandell F, McClain M, et al. Changes in sleep position during infancy: a prospective longitudinal assessment. JAMA 1998;280:336-40.

22. Conners CK, Sitarenios G, Parker JD, Epstein JN. The revised Conners' Parent Rating Scale (CPRS-R): factor structure, reliability, and criterion validity. J Abnormal Child Psychol 1998;26:257-68.

23. Chervin RD, Hedger K, Dillon JE, Pituch KJ. Pediatric sleep questionnaire (PSQ): validity and reliability of scales for sleep-disordered breathing, snoring, sleepiness, and behavioral problems. Sleep Med 2000;1: 21-32.
24. Korkman M, Kirk U, Kemp S. NEPSY: a developmental neuropsychological assessment. San Antonio (TX): The Psychological Corporation; 1998.
25. Jacobson J, Jacobson SW, Padgett R. Effects of prenatal PCB exposure on cognitive processing efficiency and sustained attention. Devel Psychol 1991;28:297-306.
26. Wechsler D. Wechsler Preschool and Primary Scale of Intelligence-Revised. New York: The Psychological Corporation; 1989.
27. Rechtschaffen A, Kales A. A manual of standardized terminology: techniques and scoring system for sleep stages of human subjects. Los Angeles (CA): UCLA Brain Information Service/Brain Research Institute; 1968.
28. Marcus CL, McColley SA, Carroll JL, Loughlin GM, Smith PL, Schwartz AR. Upper airway collapsibility in children with obstructive sleep apnea syndrome. J Appl Physiol 1994;77:918-24.
29. Young T, Palta M, Dempsey J, Skatrud J, Weber S, Badr S. The occurrence of sleep disordered breathing among middle-aged adults. N Engl J Med 1993;328:1230-5.
30. Gottlieb DJ, Yao Q, Redline S, Ali T, Mahowald M. Does snoring predict sleepiness independently of apnea and hypopnea frequency? Am J Respir Crit Care Med 2000;162:1512-7.
31. Baghurst PA, McMichael AJ, Wigg NR, Vimpani GV, Robertson EF, Roberts RJ, et al. Environmental exposure to lead and children's intelligence at the age of seven years. The Port Pirie Cohort Study. N Engl J Med 1992;327: 1279-84.
32. Wasserman GA, Liu X, Lolacono NJ, Factor-Litvak P, Kline JK, Popovac D, et al. Lead exposure and intelligence in 7-year-old children: the Yugoslavia Prospective Study. Environ Health Perspect 1997;105:956-62.
33. Schwartz J. Low-level lead exposure and children's IQ: a meta-analysis and search for a threshold. Environ Res 1994;65:42-55.
34. Ali NJ, Pitson D, Stadling JR. Natural history of snoring and related behaviour problems between the ages of 4 and 7 years. Arch Dis Childhood 1994;71:74-6.
35. Gerstadt CL, Hong YJ, Diamond A. The relationship between cognition and action: performance of children 3 1/2-7 years old on a Stroop-like day-night test. Cognition 1994;53:129-53.
36. Diamond A, Taylor C. Development of an aspect of executive control: development of the abilities to remember what I said and to "do as I say, not as I do". Dev Psychobiol 1996;29:315-34.