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Article *in* Pediatric Pulmonology · April 2004

DOI: 10.1002/ppul.10453 · Source: PubMed

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Pediatric Pulmonology 37:330–337 (2004)

Reduced Neurocognition in Children Who Snore

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Summary. Obstructive sleep apnea syndrome (OSAS) has been associated with reduced neurocognitive performance in children, but the underlying etiology is unclear. The aim of this study was to evaluate the relationship between hypoxemia, respiratory arousals, and neurocognitive performance in snoring children referred for adenotonsillectomy. Thirteen snoring children who were referred for evaluation regarding the need for adenotonsillectomy to a children's hospital otolaryngology/respiratory department underwent detailed neurocognitive and polysomnographic (PSG) evaluation. PSGs were evaluated for respiratory abnormalities and compared with 13 nonsnoring control children of similar age who were studied in the same manner. The snoring children had an obstructive respiratory disturbance index within normal range (mean obstructive apnea/hypopnea index, 0.6/hr). Despite this, several domains of neurocognitive function were reduced in the snoring group. These included mean verbal IQ scores (snorers 92.6 vs. nonsnorers 110.2, $P < 0.001$), mean global IQ scores (snorers 96.7 vs. nonsnorers 110.2, $P < 0.005$), mean selective attention scores (snorers 46.4 vs. nonsnorers 11.8, $P < 0.001$), mean sustained attention scores (snorers 8.0 vs. nonsnorers 2.2, $P = 0.001$), and mean memory index (snorers 95.2 vs. nonsnorers 112.1, $P = 0.001$). There was a direct relationship between number of mild oxygen desaturations of $\geq$3%, obstructive hypopneas with $\geq$3% oxygen desaturations, and respiratory arousals and severity of neurocognitive deficits, with the greatest effect being on memory scores. The disruption of sleep in snoring children produced by relatively mild changes in oxygen saturation or by increases in respiratory arousals may have a greater effect on neurocognitive function than hitherto appreciated. A possible explanation for these neurocognitive deficits may be the combination of the chronicity of sleep disruption secondary to snoring which is occurring at a time of rapid neurological development in the first decade of life. Future studies need to confirm the reversal of these relatively mild neurocognitive decrements post adenotonsillectomy. **Pediatr Pulmonol. 2004; 37:330–337.**

Key words: neurocognitive function; sleep; children; obstructive sleep apnea syndrome.

INTRODUCTION

Obstructive sleep apnea syndrome (OSAS) affects up to 2.5% of children and, if severe, causes hypoxemia, hypercarbia, and sleep fragmentation resulting in developmental delay, cor pulmonale, growth failure, and systemic hypertension.[1] While these sequelae have been extensively documented over the last four decades, attention has focused on the severe end of the OSAS spectrum, with less understanding of potential sequelae at the milder end. There is now a growing awareness that sleep may play an important role in learning, by affecting the consolidation and integration of memory, with slow-wave sleep facilitating the assimilation of new knowledge, while REM sleep facilitates the accommodation of new memories into neocortical association networks.[2] The disruption of children's normal sleep architecture by the physiological sequelae of relatively mild upper airway obstruction may

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Received 12 December 2002; Revised 12 August 2003; Accepted 12 August 2003.

DOI 10.1002/ppul.10453
Published online in Wiley InterScience (www.interscience.wiley.com).

interfere with this learning process and result in daytime neurocognitive sequelae.

Over the past 20 years, many studies of adults with OSAS reported reductions in intellectual ability, sustained attention, executive cognitive function, and memory.[3] Correlational studies[4–6] suggest that these neurocognitive deficits in adult OSAS are associated with sleep fragmentation and nocturnal hypoxia in a dose-dependent fashion. The treatment of adult OSAS with continuous positive airway pressure (CPAP) results in improved daytime functioning, although there is some evidence that frontal lobe deficits such as mental flexibility and verbal fluency may not be completely reversible.[7,8]

There is emerging evidence that OSAS in children affects similar neurocognitive and behavioral domains to those of adults, especially in the interrelated areas of attentional capacity, memory, intelligence, and learning.[9] However, relatively few studies directly examined the relationship between the physiological changes caused by OSAS during children's sleep and subsequent neurocognitive deficits. Several studies instead reported improvements in learning and behavior following treatment of OSAS by adenotonsillectomy, thereby implying a causal relationship. Guilleminault et al.[10] found an improvement in school performance in 4 children with severe OSAS following adenotonsillectomy, while in a second study of 26 children with OSAS,[11] adenotonsillectomy resulted in an improvement in behavior with correction of hypoxemia and sleep fragmentation secondary to movement. Gozal[12] demonstrated that when OSAS was corrected in 24 children whose academic ranking was in the lowest 10th percentile, their school grades significantly improved.

The aim of this study was to investigate the relationship between 1) those neurocognitive domains previously found to be most affected in childhood OSAS (IQ, memory, and attentional capacity), and 2) the polysomnographic findings of hypoxemia, respiratory arousal, and obstructive hypopnea in a group of children with a history of snoring who were referred for evaluation regarding the need for adenotonsillectomy.

MATERIALS AND METHODS

Participants

The findings reported here are of 13 snoring and 13 nonsnoring control children who had both neurocognitive and polysomnographic parameters evaluated at time of referral. They formed part of a larger study group (outlined below) of 32 children (16 snorers and 16 controls) whose neurocognitive findings were only published.[13]

The original cohort of 16 Caucasian children (9 females, 7 males) had been referred by their general practitioner for evaluation of snoring and the need for adenotonsillectomy to the Departments of Otolaryngology and Pulmonary Medicine, Women's and Children's Hospital, Adelaide, South Australia. All were thought to have significant OSAS following a clinical history and examination by their otolaryngologist or pulmonary physician. Two children had other medical problems. One required prophylactic medication for asthma, and the second was known to have small laryngeal polyps which were not thought to significantly contribute to the severity of upper airway obstruction

Sixteen healthy nonsnoring controls (9 females, 7 males) were also recruited. These were friends of the index snoring patients or identified through newspaper advertisements.

All 32 children underwent detailed neurocognitive testing, and 26 children underwent a polysomnogram (PSG). The latter group form the basis of this report. Of the 6 children (3 with snoring and 3 controls) who did not have a PSG, 4 declined, and the 2 remaining children lived a significant distance from the hospital and were unable to attend the sleep laboratory. The original group of 32 children was matched for age (within 6 months) and gender. The neurocognitive tests were age-normed. Informed consent was obtained from the parents of all children and, where appropriate, the children themselves. The protocol was approved by the Research Ethics Board of the Women's and Children's Hospital.

Polysomnography

Nocturnal polysomnographic recordings were obtained using the Compumedics S Series Sleepwatch System (Melbourne, Australia). Children attended the Sleep Laboratory with a parent approximately 1 hr before their usual bedtime. No sedation was used, and the following parameters were recorded continuously overnight using the appropriate signal sampling and filtering protocols: electroencephalogram (C_3/A_2 or C_4A_1), bilateral electrooculograms, electromyograms (submental and intercostal), electrocardiograms, chest wall and abdominal movement by respiratory inductance plethysmography (RIP; Respitrace, Ambulatory Monitoring, Inc., New York), oxygen saturation (SaO_2; Nellcor N200, Van Nuys CA), transcutaneous carbon dioxide (T_cCO_2; TINA, Radiometer Pacific), oronasal airflow (three-pronged thermistor), and sleeping position (position sensor).

A parent slept in the bedroom in a separate bed, and recordings were monitored continuously by an experienced paediatric polysomnography technician who documented sleep behavior and the presence of snoring. All data were digitized and stored on computer disc for subsequent analysis.

Polysomnographic Scoring

All polysomnograms were analyzed and scored manually by an experienced sleep technician who was unaware of the diagnostic category of the individual study. Sleep

architecture was staged using standard criteria.[14] Movement time was scored as a separate category and was not included in either sleep or awake time. Epochs were scored as movement if the EEG and EOG signals were obscured for greater than 50% of the epoch by muscle tension or artifacts associated with movement of the child.[14] Time spent in stages I–IV and REM were calculated and expressed as percentage of total sleep time (TST). Respiratory arousal and total arousal indices were defined according to the criteria of Mograss et al.,[15] and a respiratory arousal index was calculated as number of arousals secondary to respiratory events per hour of sleep.

Obstructive apnea was defined as the presence of chest wall and abdominal movement in the absence of oronasal airflow which lasted longer than two respiratory cycles. The number of obstructive apneas per hour of sleep constituted the obstructive apnea index. Apneas containing both central and obstructive elements were scored as mixed apneas and were included in the obstructive index.

Obstructive hypopnea was defined as a reduction of greater than 50% in the amplitude of the RIP signal and/or oronasal airflow (associated with paradoxical chest wall movement) and a decrease of 3% or greater in SaO_2. The apnea hypopnoea index (AHI) was defined as the number of obstructive apneas, mixed apneas, and obstructive hypopneas per hour of sleep associated with a 3% or greater oxygen desaturation.

Central apnea was defined as the cessation of both airflow and chest wall and abdominal movement. Those exceeding 20 sec or those associated with a 3% or greater oxygen desaturation or bradycardia were counted.

Neurocognitive Assessment

A complete description of the neurocognitive testing is reported in our companion paper.[13] In brief, all children in this study were tested on a battery of validated neurocognitive tests on nonschool days within 8 weeks of polysomnographic testing. The following tests of intelligence, memory, and attention were administered over one session in the order detailed below.

Intelligence

Intelligence (IQ) estimates were obtained using the Wechsler Pre-School and Primary Scale of Intelligence—Revised (WPPSI-R)[16] for children less than 6 years old, and the Wechsler Intelligence Scale for Children—Third Edition (WISC-111) for children greater than 6 years old.[17] These are standardized, individually administered tests that yield three intelligence measures: verbal IQ (VIQ), performance IQ (PIQ), and a composite (verbal + performance IQ) global IQ (GIQ). These measures have a mean of 100 (SD = 15).

Memory

Memory was assessed using the Wide Range Assessment of Memory and Learning (WRAML).[18] Four subsets of the WRAML composing the Memory Screening Index (MSI) Scale were administered: picture memory, verbal learning, design memory, and story memory. The MSI has a mean of 100 (SD = 15).

Attention

Attention was measured using the Auditory Continuous Performance Test (ACPT).[19] The children were required to indicate the presence of a target word during six consecutive presentations via audiotape of a 96-item word list containing 76 distracter words and the target word repeated 20 times. Two measures of attention were obtained: 1) selective attention (missed target words plus mistaken words), and 2) sustained attention (first and final trial error score difference). Before testing, children were given a basic hearing test followed by a practice trial. Higher ACPT selective and sustained attention scores are indicative of impaired attention. Because of the limited normative data, raw ACPT scores were used in the analyses.

Statistical Analysis

Results are expressed as mean ($\pm$SD) for continuous data. Effect sizes were calculated by expressing mean differences in performance scores between snoring and nonsnoring children as a proportion of snoring children's SD. This allowed quantification of the extent of performance decrement. Where appropriate, independent *t*-tests and chi-square tests were used to assess group differences in demographic variables. Mann-Whitney tests were utilized to assess differences in neurocognitive and polysomnographic variables. Spearman correlations were calculated to test the association between neurocognitive and polysomnograpic variables. F-tests were used to test for associations between neurocognitive variables and the following polysomnographic variables: $\geq$3% oxygen desaturations, respiratory arousals associated with $\geq$3% oxygen desaturations, and both obstructive hypopneas with $\geq$3% desaturations per hour of total sleep and per hour of REM sleep. Because of the well-documented relationship between socioeconomic status and IQ,[20] the residuals of socioeconomic status on neurocognitive function were used as dependent variables within an ANCOVA analysis. Given the small subject numbers, the highest occupation of either father or mother was used to represent socioeconomic status, which was determined from demographic data using criteria provided by the Australian Bureau of Statistics.[21] In view of the small subject numbers, the effect of gender was not examined. Statistical significance was set at the 0.05 level. No

adjustment was made for multiple comparisons, since the assumption underlying these adjustments (independent tests) is clearly untenable, given the close relationship between neurocognitive variables. However, the total number of tests is apparent in the tables, allowing individual interpretation of unadjusted significance levels.

RESULTS

Demographic

Both groups of children were of comparable age (mean (SD) snoring children = 6.9 (1.2) years, range 5.7–8.9 years, and controls = 7.6 (1.6) years, range 5.3–10.7 years), and independent *t*-tests revealed no significant age difference (t (24) = 1.8, ns). Between the snoring and control groups of children there were no statistically significant differences (chi-square) in proportions of gender; highest parental occupation (in categories of professional, management, skilled, or unskilled/semiskilled); highest maternal occupation (in categories of professional, management, skilled, unskilled/semiskilled, or home duties); and schooling (state or private).

Neurocognitive Performance

The mean (SD) neurocognitive test scores are given in Table 1. As indicated by Mann-Whitney analyses, snoring children showed significantly more impaired memory and attention performance and, apart from performance IQ, lower intelligence scores. The following effect sizes were observed: VIQ = 1.51, PIQ = 0.61, GIQ = 1.24, MSI = 3.44, selective attention = 4.19, and sustained attention = 2.08. To control for the possibility that these group differences might be explained by socioeconomic status,[20] parent's socioeconomic status was entered as a covariate in an analysis of covariance (ANCOVA) in further tests for group differences. After controlling for social class within the ANCOVA model, all previously identified group differences remained significant.

Polysomnography

Polysomnographic details are given in Table 2. In general, snoring children had only mild polysomnographic changes of OSAS with relatively few oxygen desaturations, but paradoxical chest wall movement was noted during REM sleep in 6 snoring children and in none of the nonsnoring controls. The group differences for obstructive and central apneas did not reach statistical significance. However, snoring children did show a significantly greater total number of $\geq$3% oxygen desaturations per hour of total sleep and per hour of REM sleep, and a significantly greater number of obstructive hypopneas associated with $\geq$3% oxygen desaturations per hour of total sleep and, likewise, per hour of REM sleep. No significant group differences were observed in sleep stages.

Relationship Between Polysomnographic and Neurocognitive Variables

For the combined patient groups, Spearman rho correlational results are reported in Table 3a. In general, increased number of oxygen desaturations $\geq$3% and respiratory arousals were associated with greater impairment of neurocognitive performance. Specifically, we found that children with a greater number of $\geq$3% oxygen desaturations/hour of total sleep had more impaired MSI and selective attention scores, while those with a greater number of $\geq$3% oxygen desaturations/hour of REM sleep had reduced MSI, GIQ, and selective and sustained attention scores. Those children with a greater number of obstructive hypopneas with $\geq$3% oxygen desaturation per hour of total sleep had reduced MSI scores, and those with a greater number of obstructive hypopneas in REM with $\geq$3% oxygen desaturations had reduced PIQ, GIQ, and selective and sustained attention scores. Finally, those with a greater number of respiratory arousals in REM sleep associated with $\geq$3% oxygen desaturations had reduced MSI, GIQ, and selective attention scores.

TABLE 1—Comparison of Mean (SD) Values for Neurocognitive Variables (Mann-Whitney U Analysis)

Neurocognitive variable	Snoring children (n = 13)	Control children (n = 13)	*P*-value
Intelligence (WPPSI-R and WISC-3)			
Verbal IQ	92.6 (8.9)	110.2 (11.6)	<0.001
Performance IQ	101.4 (12.6)	108.5 (11.7)	ns
Global IQ	96.7 (9.6)	110.2 (10.9)	<0.005
Memory (WRAML)			
Memory screening index	95.2 (15.7)	112.1 (4.9)	0.001
Attention (ACPT)[1]			
Selective attention	46.4 (21.3)	11.8 (8.3)	<0.001
Sustained attention	8.0 (5.1)	2.2 (2.8)	0.001

[1]Higher scores indicate more impaired performance; ns, nonsignificant.

TABLE 2—Mean (SD) Polysomnographic and Sleep Stage, and Fragmentation Variables: *P*-Values From Mann-Whitney U Analyses[1]

Polysomnographic variable	Snoring children (n = 13)	Control children (n = 13)	*P*-value
Sleep stage			
Total sleep time (hr)	7.84 (0.92)	7.17 (0.83)	ns
NREM (% TST)	73.8 (4.2)	75.2 (3.7)	ns
REM (% TST)	26.2 (4.2)	24.8 (3.7)	ns
Stage 1 (% TST)	4.4 (5.3)	2.8 (1.9)	ns
Stage 2 (% TST)	46.0 (7.1)	45.1 (7.5)	ns
Stage 3 (% TST)	5.4 (1.6)	5.7 (2.1)	ns
Stage 4 (% TST)	17.9 (4.3)	21.7 (5.6)	ns
Number of ≥3% O_2 desaturations			
Total sleep (no./hr)	1.15 (0.87)	0.42 (0.38)	<0.05
NREM (no./hr)	0.50 (0.68)	0.33 (0.53)	ns
REM (no./hr)	3.11 (3.15)	0.74 (0.60)	0.01
Apnea/hypopnea with ≥3% oxygen desaturations			
Obstructive hypopnea (no./hr)	0.50 (0.66)	0.03 (0.06)	0.01
Obstructive hypopnea (no./hr NREM)	0.11 (0.19)	0.01 (0.04)	ns
Obstructive hypopnea (no./hr REM)	1.56 (2.20)	0.09 (0.23)	<0.05
Obstructive apnea/hypopnea (no./hr)	0.60 (0.90)	0.03 (0.06)	0.01
Obstructive apnea (no./hr)	0.07 (0.19)	0.00 (0.00)	ns
Central apnea (no./hr)	0.19 (0.31)	0.16 (0.23)	ns
Respiratory arousals NREM with >3% O_2 desaturation (no./hr)	0.20 (0.26)	0.07 (0.19)	ns
Respiratory arousals REM with ≥3% O_2 desaturation (no./hr)	2.01 (2.55)	0.44 (0.54)	ns
Total respiratory arousals with ≥3% O_2 desaturation (no./hr)	0.69 (0.79)	0.16 (0.16)	<0.05
Total respiratory arousals (no./hr)	3.41 (2.82)	1.53 (2.32)	ns
Total arousal index	18.4 (6.12)	13.9 (4.49)	<0.05
O_2 nadir (%)	91.9 (6.3)	94.6 (1.4)	ns
Peak T_cCO_2 (mm μg)	52.9 (4.7)	48.9 (2.7)	0.01

[1]ns, nonsignificant; TST, total sleep time.

To control for the effect of socioeconomic status on neurocognitive performance, parental socioeconomic status was included as a partial correlate in additional correlational analyses. The subsequent partial correlational results are reported in Table 3b. After controlling for parental socioeconomic status, analyses indicated that reduced MSI scores were significantly associated with a higher number of ≥3% oxygen desaturations per hour of total sleep, while reduced VIQ, GIQ, and MSI scores were all associated with a higher number of ≥3% oxygen desaturations per hour in REM sleep. Obstructive hypopneas with ≥3% desaturation per hour of total sleep and per hour of REM sleep were significantly associated with reduced GIQ and MSI scores. This relationship was more

TABLE 3a—Correlations (Spearman r-Value) Between Neurocognitive and Selected Polysomnographic Variables[1]

	Neurocognitive variable					
Polysomnographic variable	Verbal IQ	Performance IQ	Global IQ	Memory screening index	Selective attention	Sustained attention
≥3% O_2 desaturations						
Per hr of total sleep	−0.27	−0.21	−0.18	−0.45*	0.44*	0.32
Per hr REM sleep	−0.39	−0.34	−0.41*	−0.45*	0.52**	0.42*
Associated with respiratory arousals/hr Sleep	−0.32	−0.28	−0.26	−0.50**	0.41*	0.38
Associated with respiratory arousals/hr REM sleep	−0.32	−0.36	−0.39*	−0.41*	0.42*	0.35
Obstructive hypopneas with ≥3% O_2 desaturations						
Per hr total sleep	−0.37	−0.31	−0.32	−0.40*	0.38	0.35
Per hr REM sleep	−0.35	−0.50**	−0.44*	−0.36	0.52**	0.40*

[1]Snoring and control children were combined, total n = 26.
*$P < 0.05$.
**$P < 0.01$.

TABLE 3b— Correlation (r Value) Between Neurocognitive and Selected Polysomnographic Variables After Controlling for Parental Socioeconomic Status[1]

	Neurocognitive variable					
Polysomnographic variable	Verbal IQ	Performance IQ	Global IQ	Memory screening index	Selective attention	Sustained attention
≥3% O_2 desaturations						
Per hr of total sleep[2]	−0.33	−0.23	−0.33	−0.68****	0.19	−0.07
Per hr of REM sleep	−0.45*	−0.45*	−0.52**	−0.70****	0.36	−0.04
Associated with respiratory arousals/hr sleep	−0.38	−0.41*	−0.46*	−0.72****	0.25	−0.10
Associated with respiratory arousals/hr REM sleep	−0.43*	−0.47*	−0.53**	−0.71****	0.23	−0.08
Obstructive hypopneas with ≥3% O_2 desaturations						
Per hr Total Sleep	−0.39*	−0.37	−0.45*	−0.67****	0.18	−0.10
Per hr REM sleep	−0.38	−0.46*	−0.49*	−0.64****	0.28	−0.05

[1]For these analyses, highest parental occupation was entered as a covariate and neurocognitive measures as dependent variables in a series of ANCOVA tests. Residuals from these analyses were then correlated with selected polysomnographic variables.
[2]Selected raw data and regressions plotted in Figure 1.
*$P < 0.05$.
**$P < 0.01$.
****$P < 0.001$.

striking when respiratory arousals per hour of REM sleep associated with ≥3% oxygen desaturations were examined (see Table 3b and Figure 1).

In summary, after controlling for socioeconomic status, a significant negative association was observed between relatively mild nocturnal oxygen desaturation, obstructive hypopnea with associated mild hypoxemia, disrupted sleep architecture with respiratory arousals, and intelligence and memory, but not attention.

DISCUSSION

The principal finding of this study is that compared to nonsnoring controls, snoring children awaiting adenotonsillectomy showed a wide range of mild neurocognitive deficits which were associated with disruption of sleep by episodes of mild hypoxemia and respiratory arousal.

Increasing evidence over the past decade suggests that neurocognitive performance and behavior is impaired in children with OSAS. In general, children with OSAS show reduced attentional capacity,[13,22–24] impaired learning and school performance,[12] and increased problematic behavior,[11,24,25] while at the more severe end of the spectrum, reduced memory[26] and reduced intelligence were found.[26,27] Although the majority of snoring children in the current study performed within normal range, compared to controls and consistent with previous findings, they showed reduced intelligence, memory, and attention. In addition, except for attention, these deficits remained after controlling for socioeconomic class: a recognized confounding factor when comparing group differences in neurocognitive performance.[20] It is to be noted that adults and children with OSAS show similar neurocognitive deficits. However, compared to adults with OSAS of similar severity,[3] much greater effect sizes were observed in snoring children in the present study.

In adults with OSAS, sleep fragmentation and hypoxia were identified as determinants for neurocognitive deficits.[8] It is reasonable to assume that the same may be true for children. We found that children with a greater number of ≥3% oxygen desaturations in REM sleep (with or without obstructive hypopnea or respiratory arousal) tended to have more reduced global intelligence, memory (excluding obstructive hypopnea), selective attention, and sustained attention performance. In addition, after socioeconomic class was controlled for in further analyses, significant negative relationships remained for intelligence and memory but not attention. The present findings are consistent with those of Rhodes et al.,[26] who reported in 14 obese children an inverse relationship between the apnea/hypopnea index and both learning performance and memory but not general intelligence. Likewise, preliminary data reported by Lewin et al.[27] showed that the severity of OSAS in 7 children with moderate-severe OSAS was inversely correlated with cognitive function. Finally, the findings of Owens et al.[28] in 18 children aged 5–12 years demonstrated that those with mild (RDI ≤ 4; n = 9) compared to moderate-severe (RDI ≥ 5; n = 9) OSAS had significantly more errors on a test of attention-impulsivity, while the moderate/severe group had more memory difficulties. The impairment of neurocognitive domains in children with OSAS is also supported by reports of its improvement if OSAS is reversed. This includes evidence from both parental report[10,29] and standardized testing[22,23,30] that adenotonsillectomy in children with OSAS reduces symptomatology, and that this is accompanied by a significant improvement in behavior,[23,30] cognitive function,[22] and

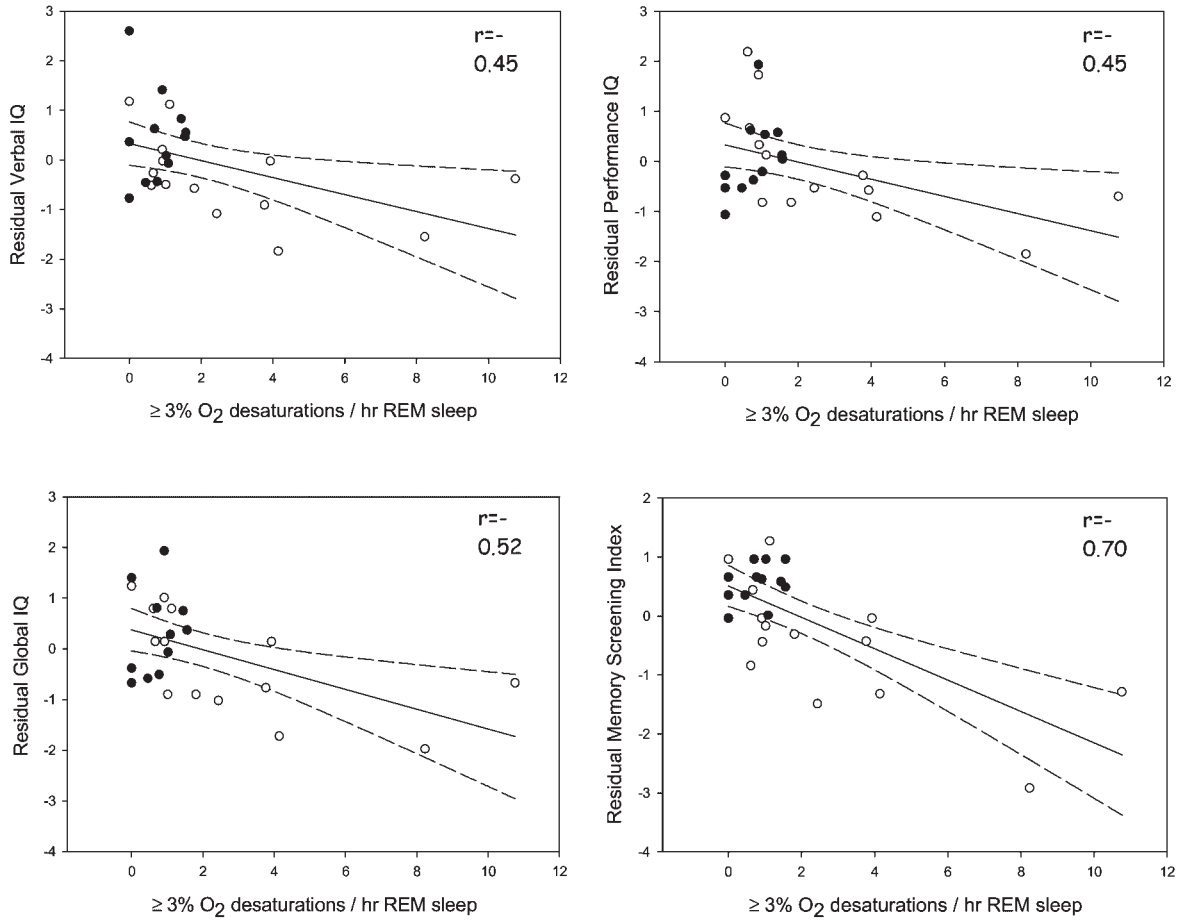

Fig. 1. Significant correlations are present between neurocognitive variables and number of desaturations during REM sleep, after allowing for highest parental occupation (ANCOVA). Solid circles, control children; open circles, snoring children. Regression line and 95% confidence intervals are shown. r-values and significance levels noted are shown in Table 3b.

learning.[12] Together, these reports and the findings of the present study suggest that children who snore may be at greater risk for reduced neurocognitive performance than is generally appreciated.

Many physicians (including the authors initially) would consider mild degrees of hypoxemia or fragmentation of sleep by respiratory arousals as an unlikely explanation for changes in neurocognitive performance. However, we suggest that the association may be explained by the combination of the cumulative effect of the chronicity of sleep architecture disruption over many years and the simultaneous rapid development of the child's neuronal synaptic network. If true, the present findings of a significant association between mild polysomnographic changes in sleep architecture and reduced neurocognitive performance point to the potentially pivotal role of sleep architecture in facilitating the development of child memory and learning. Beebe and Gozal[31] proposed that the cognitive and behavioral deficits seen in children with OSAS are secondary to prefrontal cortex (PFC) dysfunction caused by sleep disruption, hypoxemia, and hypercarbia. The PFC is well-known to play an important role in executive functioning including cognitive flexibility, reasoning, and memory. As discussed by Beebe and Gozal,[31] unlike the majority of other regions of the brain, the PFC shows decreased activity during all sleep stages, and appears to functionally disconnect from other brain regions during sleep, allowing it to "recalibrate." They suggest that the physiological sequelae of OSAS alter the metabolism and neurochemistry of this vulnerable region. Preliminary evidence in support of this hypothesis is the finding by Gozal et al.[32] in the rat model of OSAS that 2 weeks' exposure to intermittent hypoxia during sleep in adult rats resulted in neuronal apoptosis in the hippocampus and overlying cortex, and in addition, that the severity of apoptosis was associated with impaired performance on cognitive tests of spatial-learning ability. In summary, because of the PFC's relatively late maturity compared to other brain regions, it may be more vulnerable to the disruptive physiological effects of hypoxemia, hypercarbia, and sleep fragmentation, especially if prolonged.

It is important to outline the limitations of the current study. Subject numbers were small, and children were not randomly selected from the community but were referred to a specialized children's hospital for assessment of snoring. Patient diagnosis was known at time of psychological testing, and children were not matched exactly for socioeconomic status with more control subjects coming from higher socioeconomic backgrounds. Therefore, it remains possible that differences in socioeconomic status may explain some of the differences seen in neurocognitive function between the snoring and nonsnoring groups. However, when the effect of socioeconomic status was controlled for in the statistical analysis, clear differences in neurocognitive scores between the two groups remained.

In conclusion, the results of the present study indicate in snoring children that increased nocturnal respiratory arousal levels, and hypoxemia with resultant sleep architecture disruption, are associated with reduced neurocognitive performance. Future studies will need to confirm that these deficits are corrected by adenotonsillectomy.

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