Snoring, Intermittent Hypoxia and Academic Performance in Primary School Children

Michael S. Urschitz, Anke Guenther, Esther Eggebrecht, Judith Wolff, Pilar M. Urschitz-Duprat, Martin Schlaud, and Christian F. Poets

Department of Neonatology, University Hospital of Tuebingen, Tuebingen; Departments of Pediatric Pulmonology and Neonatology, and Epidemiology, Social Medicine and Health System Research, Hannover Medical School, Hannover, Germany; and Department of Pediatrics, Division of Neonatology, Vienna General Hospital, University of Vienna, Vienna, Austria

Sleep-disordered breathing is associated with impaired attention and neurocognitive deficits. We assessed the association of snoring and intermittent hypoxia with poor academic performance in third grade school children (1,144 children). Snoring frequency and intermittent hypoxia were investigated using parental questionnaire and nocturnal home pulse oximetry. Intermittent hypoxia was specified as desaturation events of 90% or less pulse oximeter saturation. Poor academic performance was defined as grade 4–6 on a six-point scale (i.e., approximately the lowest quintile grades) in mathematics, science, reading, spelling, and/or handwriting in the most recent school report. Snoring "always" was significantly associated with poor academic performance in mathematics (odds ratio; 95% confidence interval: 3.6; 1.3–10.1), science (4.3; 1.3–14.6), and spelling (3.5; 1.2–10.3). Snoring "frequently" was also significantly associated with poor academic performance in mathematics (2.4; 1.3–4.7) and spelling (2.0; 1.04–3.8). A significant relationship between snoring and poor academic performance was also found in children without intermittent hypoxia, whereas intermittent hypoxia did not show an independent association with poor academic performance. Thus, habitual snoring (i.e., snoring frequently or always) was associated with poor academic performance in these primary school children.

Keywords: sleep-disordered breathing; oximetry; snoring; hypoxia; learning disorders

Sleep-disordered breathing in children ranges from primary snoring (i.e., snoring without intermittent hypoxia, hypercarbia, or repeated arousal) through upper airway resistance syndrome (i.e., snoring with labored breathing and repeated arousal but without gas exchange abnormalities) to obstructive sleep apnea–hypopnea syndrome ([OSAHS]; snoring with apnea, intermittent hypoxia, hypercarbia, and repeated arousal) (1). In all these categories, the primary symptom is habitual snoring (i.e., snoring on most nights).

Consequences of pediatric sleep-disordered breathing have only been studied for OSAHS and include cardiovascular complications (2), failure to thrive (3), behavioral disturbance, excessive daytime sleepiness, attention-deficit/hyperactivity disorder, and poor learning (4–6). One study evaluating first graders who were in the lowest 10th percentile academically found a six to nine times higher prevalence of OSAHS (7).

The precise mechanism(s) responsible for neurocognitive impairment in sleep-disordered breathing is unclear but includes intermittent hypoxia, repeated arousal, and alveolar hypoventilation resulting in hypercarbia (8). If repeated arousal is the primary mechanism, then not only "classic" OSAHS but also habitual snoring without intermittent hypoxia should be associated with neurocognitive impairment (9). This, however, has not yet been systematically studied.

We performed a population-based cross-sectional study on the prevalence of sleep-disordered breathing in primary school children and its association with poor academic performance. Enrolled children were screened for signs and symptoms of sleep-disordered breathing and for intermittent hypoxia during sleep using a questionnaire and nocturnal home pulse oximetry. Children with outlying results on either screening method subsequently underwent nocturnal home polysomnography. We report here on the association of snoring and intermittent hypoxia with poor academic performance. Some results of this study have been published in abstract form (10).

METHODS

The recruitment strategy and comparisons for representativeness are described elsewhere (Schlaud and coworkers, personal communication). In short, 27 of the 59 public primary schools located within the city limits of Hannover, Germany, were selected at random within strata of socioeconomic status. After approval by the institutional review board and the regional directorate of education, all children attending third grade classes in these schools ($n = 1{,}760$) were identified. Pupils were contacted in their classroom by two investigators (P.M.U.-D. and M.S.U.) between February 2001 and December 2001. A cover letter explaining the study, an informed consent form, and a sleep-disordered breathing questionnaire were given to the children to be filled in by their parents. Questionnaires were collected by the classroom teacher and picked up by a study crew member 1–2 weeks after the initial visit.

Children were screened using a modified version of Gozal's (7) sleep-disordered breathing questionnaire. Detailed information on the questionnaire is presented elsewhere (Schlaud and coworkers, personal communication). Snoring was investigated with the following question: Does your child snore? Responses were rated on a four-point rating-scale ranging from "never" and "occasionally" to "frequently" and "always" (11). Parental education was investigated separately for each parent. The highest graduation (four-point scale: no graduation/primary school, secondary school, high school, college/university) was scored.

All children underwent nocturnal home pulse oximetry. Detailed information on this method is published elsewhere (12). In short, recordings of oxygen saturation (Sp_{O2}), pulse rate, and signal quality were obtained after a study nurse had explained the device (Masimo SET, Irvine, CA) to the children in their classroom. Children were instructed to start the recording at bedtime and terminate it in the morning. Once downloaded to a PC, total and artifact-free recording time, as well as falls in Sp_{O2} by 4% or more were determined. Desaturation events were defined as falls in Sp_{O2} to 90% or less, desaturation clusters as five or more falls in Sp_{O2} by 4% or more occurring within a 30-minute period (13). Children were categorized as having desaturation events or clusters if at least one such event was present.

On the basis of the previous term's report (including grades on a six-point scale: 1 for "outstanding" and 6 for "failed"), poor academic performance was defined as grade 4 or worse, or requirement for special assistance, for mathematics, science, reading, spelling, and handwriting.

(*Received in original form December 2, 2002; accepted in final form May 15, 2003*)

Supported by research grant from the Hans Meineke Foundation, Hannover, Germany (P.M.U.-D.); oximeter sensors were provided by Masimo Corp., Irvine, CA.

Correspondence and requests for reprints should be addressed to Christian F. Poets, M.D., Department of Neonatology, University Hospital of Tuebingen, Calwerstr. 7, 72076 Tuebingen, Germany. E-mail: christian-f.poets@med.uni-tuebingen.de

Am J Respir Crit Care Med Vol 168. pp 464–468, 2003
Originally Published in Press as DOI: 10.1164/rccm.200212-1397OC on May 28, 2003
Internet address: www.atsjournals.org

Statistical Analysis

All analyses were done with statistical software (Statistical Package for the Social Science, release 11.0 for Windows; SPSS; Chicago, IL). Descriptive statistics were used to summarize subject characteristics and questionnaire results. Comparisons between distributions were done using Pearson's χ^2 test and χ^2 test for trend where appropriate. A p value less than 0.05 was considered statistically significant. To quantify potential associations between snoring frequency, desaturation events or clusters, and poor academic performance, odds ratios (OR) and their 95% confidence intervals (95% CI) were calculated using unconditional logistic regression. Logistic models were adjusted for gender, age (continuous variable), and maternal and paternal education (two categorical variables). To adjust for different rating styles of teachers, class membership was entered as a dummy variable.

RESULTS

Subject Characteristics and Poor Academic Performance

A total of 1,144 children (65.0%; study sample) participated and returned a completed questionnaire. There were 559 girls (48.9%); mean (SD) age was 9.6 years (0.7). Most children (n = 681; 59.5%) were 9 years old, but 213 (18.6%) and 250 (21.9) were younger and older, respectively. Information on academic performance was available at least in 1,090 children (95.7%). Using the above definitions, the prevalence of poor academic performance in our study sample was 19.1% in mathematics, 14.0% in science, 18.8% in reading, 21.8% in spelling, and 13.6% in handwriting. Except for mathematics (18.9% in boys vs. 20.3% in girls, not significant), poor academic performance was significantly more prevalent in boys (science, 17.6% vs. 11.1%; reading, 25.3% vs. 13.3%; spelling 30.3% vs. 15.1%; handwriting 21.7% vs. 6.7%; all $p < 0.01$). Poor academic performance also increased with age, which was statistically significant ($p < 0.001$) for all school subjects under study (e.g., for mathematics: 15.6%, 16.1%, and 32.8% for < 9, 9, and > 9 years of age). Children who had repeated a school year and were, therefore, older than their peers were more prone to impaired school achievement. As expected, the prevalence of poor academic performance decreased with increasing levels of parental education, which was significant for both fathers ($p < 0.001$) and mothers ($p < 0.01$). There was considerable variation in poor academic performance among children from different school classes, which was significant for all school subjects ($p < 0.05$). This finding necessitated the inclusion of class membership (as a surrogate for teacher's rating style) into the logistic regression analysis.

Poor Academic Performance and Snoring

Information on snoring was available for 1,129 children (98.7%). Of these, 410 (36.3%) never snored and 605 (53.6%) occasionally snored. Eighty-nine (7.9%) and 25 (2.2%) children were reported to snore frequently or always. There was no significant association of snoring with gender or age. Analysis of school grades revealed an increasing prevalence of poor academic performance with increasing snoring frequency, which was significant for mathematics, science, and spelling (Table 1). After adjustment for potential confounders in the multivariate analysis, snoring remained significantly associated with poor academic performance in mathematics, science, and spelling. This effect became stronger with increasing frequency of snoring (Table 2).

Intermittent Hypoxia

Of 1,144 participants, 29 children had moved or were ill at the time of the pulse oximetry recording; thus, 1,115 recordings were performed. Of these, 996 recordings (89.3%) comprised at least 5 hours of artifact-free recording time and were therefore considered sufficient for the study purpose. Mean (SD; 10th percentile) artifact-free recording time was 9.4 hours (1.2; 7.7). In total, 145 children (14.6%) had at least one desaturation event (mean number; SD; range: 2.1; 2.0; 1–11) and 223 children (22.4%) had at least one desaturation cluster (2.6; 2.5; 1–21). Desaturation events were significantly more prevalent among boys compared with girls (16.7% vs. 12.3%; $p = 0.047$). This was not found for desaturation clusters (boys vs. girls: 24.0% vs. 20.7%). There was no association between desaturation events or clusters and age. Although the prevalence of desaturation events (never snoring: 12.2%; always snoring: 14.3%) and clusters (never snoring: 19.0%; always snoring: 28.6%) increased with frequency of snoring, these associations did not reach statistical significance.

Poor Academic Performance and Intermittent Hypoxia

Children with desaturation events were at higher risk of doing poorly in all school subjects under study when compared with children without desaturation events (prevalence of poor academic performance in mathematics: 25.4% vs. 18.4%; science: 17.6% vs. 13.1%; reading: 20.4% vs. 18.2%; spelling: 24.1% vs. 21.3%; handwriting: 17.4% vs. 13.5%). These associations did not reach statistical significance; however, for mathematics it was close to ($p = 0.053$). In addition, poor academic performance was not significantly increased in children with desaturation clusters regarding any school subject under study. In the multivariate model, children with desaturation events showed a significantly increased risk of doing poorly in mathematics (OR [95% CI; p value]: 1.8 [1.06–3.0; 0.030]). After adjustment for snoring frequency, however, the significance of this association was lost (OR [95% CI; p value]: 1.5 [0.9–2.6; 0.104]). To account for the children's health status at the time of recording, all children with parentally reported signs of an acute upper respiratory tract infection were excluded. Logistic regression analysis was repeated in the remaining 753 children without any acute illness. This revealed a nonsignificant association between desaturation events and poor academic performance in mathematics (OR [95% CI; p value]: 1.5 [0.8–2.8; 0.216]).

Poor Academic Performance and Snoring in Children without Intermittent Hypoxia

To test for an independent relationship between snoring frequency and poor academic performance, this association was reinvestigated in a subgroup of children without desaturation events. Therefore, children with desaturation events were excluded from the study sample and logistic regression analysis was repeated in the remaining 851 children. In this analysis, snoring remained significantly related to poor academic performance in mathematics and spelling (Table 3).

DISCUSSION

Habitual snoring, defined as snoring frequently or always, was found in 1 in 10 of these primary school children, which is in line with other studies (14). More importantly, children who snored habitually had at least twice the risk of performing poorly at school, with this association becoming stronger with increasing snoring frequency. This relationship between habitual snoring and poor academic performance did not appear to be mediated via intermittent hypoxia, as it was not diminished after excluding children with intermittent hypoxia in an overnight study. In addition, we found a weak association between intermittent hypoxia and poor academic performance in these primary school children, which was not, however, independent of snoring.

Factors making a causal relationship more likely include a close temporal relationship, consistency and strength of association, biological plausibility, and presence of a biological gradient (15). Although data are already available to support the first four

TABLE 1. PREVALENCE OF POOR ACADEMIC PERFORMANCE IN VARIOUS SCHOOL SUBJECTS STRATIFIED BY FREQUENCY OF SNORING IN STUDY PARTICIPANTS (N = 1,129)

	Snoring Categories				
Poor Academic Performance Area	Never	Occasionally	Frequently	Always	χ^2 Test for Trend
Mathematics	66 (16.4)	112 (19.0)	25 (28.4)	12 (48.0)	$p < 0.001$
Science	51 (12.7)	75 (12.8)	18 (20.5)	10 (40.0)	$p = 0.003$
Reading	79 (19.8)	101 (17.3)	20 (22.7)	9 (36.0)	$p = 0.330$
Spelling	81 (20.5)	124 (21.5)	28 (32.6)	12 (50.0)	$p = 0.002$
Handwriting	52 (13.3)	82 (14.2)	13 (15.3)	6 (25.0)	$p = 0.215$

Data are total numbers followed by percentage in parentheses.

requirements (7, 16), our study is the first to report a clear biological gradient between snoring frequency and risk of poor academic performance. Such a dose–effect relationship was suggested in a study on sleep-disordered breathing and hyperactive behavior in children (17) and recently shown in a study on snoring and daytime sleepiness in adults (18). However, due to the cross-sectional design of the current study, evidence of causality is limited.

Potential mediators through which sleep-disordered breathing may contribute to poor academic performance are neurocognitive deficits, behavioral disturbances, daytime sleepiness, and/or hearing difficulties. Blunden and coworkers (19) found impaired attention capacity, as well as lower memory and intelligence scores, in children with habitual snoring, independent of OSAHS. They suggested that the primary deficit in habitual snoring is a reduced attention capacity, resulting in impaired memory and intelligence scores. Behavioral abnormalities like attention deficits or hyperactive behavior (4, 14, 20–22) as well as daytime sleepiness (4, 6, 14, 21) have repeatedly been reported in children with habitual snoring or OSAHS. In adults, daytime sleepiness was suggested as the primary cause of neurocognitive dysfunction in sleep-disordered breathing (23), but pediatric data do not support this contention (19). In fact, it remains unclear whether sleep-disordered breathing has a direct effect on learning or the impaired academic achievement is a phenomenon secondary to behavioral disturbance.

Poor hearing is associated with habitual snoring (14), as is recurrent otitis media (24). Both are attributable to adenotonsillar hypertrophy and are closely associated with behavioral problems at school (14, 25). One study found an association between otitis media and poor academic performance (26), others did not (27, 28). However, the overall prevalence of hearing problems appears to be low in children who snore habitually, affecting only 1 of 23 children (4.3%) in one study (5). Thus, poor hearing is unlikely to explain fully the association between habitual snoring and poor academic performance in our study.

The mechanism(s) explaining neurocognitive deficits and behavioral disturbances in children with sleep-disordered breathing is unclear. Three potential pathways, namely intermittent hypoxia, repeated arousal, and periodic or continuous alveolar hypoventilation resulting in hypercarbia are suggested (8). These physiological disturbances are thought to cause prefrontal cortical dysfunction leading to impaired cognitive execution (8). In adults, a large population-based study revealed snoring associated with daytime sleepiness independent of sleep apneas and cortical arousals but no independent relationship with arousal frequency (18). Thus, activation of the sympathetic nervous system (vegetative arousal) rather than cortical arousal was suggested to correlate with daytime sleepiness (18). Considering that academic performance is a surrogate for neurocognitive functioning in children, our findings suggest that mechanisms other than intermittent hypoxia may be more important in the relationship between snoring and neurocognitive deficits in most school children. In general, caution in interpretation is advisable when measures are colinear (intercorrelated) and when they are imperfect surrogates for "pure" measures (e.g., reported snoring frequency estimating arousal frequency vs. desaturation events estimating lifetime hypoxemic exposure). As we did not find a significant association between snoring frequency and the presence of intermittent hypoxia, colinearity did not seem to be play an important role in our study.

In our study, desaturation events to 90% Sp_{O_2} or less in an overnight study were only weakly associated with an increased risk of performing poorly in mathematics. Restriction to children without any signs of acute illness at the time of study did not change this weak association. In adults, intermittent hypoxia was found to have an influence on neurocognitive function, which was independent of cortical arousal (29, 30). An impairment in sustaining attention during repetitive arithmetic calculations was found in patients with OSAHS who had severe nocturnal hypoxia (31); this impairment was not alleviated after successful treatment, suggesting either a noncausal association or a long-lasting effect of hypoxia on brain function (early programming).

TABLE 2. ADJUSTED ODDS RATIOS FOR POOR ACADEMIC PERFORMANCE IN VARIOUS SCHOOL SUBJECTS STRATIFIED BY FREQUENCY OF SNORING IN STUDY PARTICIPANTS (N = 1,129)

	Snoring Categories			
Poor Academic Performance Area	Never (*OR*)	Occasionally *OR (95% CI; p value)*	Frequently *OR (95% CI; p value)*	Always *OR (95% CI; p value)*
Mathematics	1.0	1.2 (0.8–1.8; 0.292)	2.4 (1.3–4.7; 0.008)	3.6 (1.3–10.1; 0.017)
Science	1.0	0.8 (0.5–1.3; 0.426)	2.0 (0.9–4.3; 0.075)	4.3 (1.3–14.6; 0.017)
Reading	1.0	0.7 (0.5–1.1; 0.168)	1.8 (0.9–3.8; 0.117)	1.1 (0.4–3.4; 0.817)
Spelling	1.0	1.1 (0.7–1.5; 0.797)	2.0 (1.04–3.8; 0.038)	3.5 (1.2–10.3; 0.020)
Handwriting	1.0	1.0 (0.7–1.6; 0.925)	1.2 (0.6–2.8; 0.601)	1.8 (0.5–5.9; 0.363)

Definition of abbreviations: CI = confidence interval; OR = odds ratio.

ORs were adjusted for sex, age, maternal and paternal education, and class membership. Reference category: snoring "never."

TABLE 3. ADJUSTED ODDS RATIOS FOR POOR ACADEMIC PERFORMANCE IN VARIOUS SCHOOL SUBJECTS STRATIFIED BY FREQUENCY OF SNORING IN STUDY PARTICIPANTS WITHOUT INTERMITTENT HYPOXIA (N = 851)

	Snoring Categories			
Poor Academic Performance Area	Never (*OR*)	Occasionally (*OR* [*95% CI; p value*])	Frequently (*OR* [*95% CI; p value*])	Always (*OR* [*95% CI; p value*])
Mathematics	1.0	1.1 (0.7–2.0; 0.497)	2.8 (1.2–6.6; 0.016)	3.3 (0.9–12.6; 0.074)
Science	1.0	0.6 (0.4–1.2; 0.142)	1.5 (0.6–4.3; 0.415)	2.9 (0.6–13.1; 0.170)
Spelling	1.0	1.1 (0.7–1.7; 0.782)	2.2 (0.95–5.1; 0.066)	4.5 (1.1–18.1; 0.033)

For definition of abbreviations *see* Table 2.

Results are only presented for school subjects significantly related to snoring in the entire sample (*see* Table 2). ORs were adjusted for sex, age, maternal and paternal education, and class membership. Reference category: snoring "never."

The latter was also suggested by Gozal and Pope (16), who found a history of habitual snoring at 2–6 years of age significantly more prevalent in seventh and eighth graders who were doing poorly at school, independent of current snoring. One reason for the considerably weak relationship between intermittent hypoxia and poor academic performance observed in our study may be the low exposure prevalence to hypoxia in this sample. Only 15% of participants exhibited hypoxic episodes; our study could thus have been under-powered in this regard. Also, we only found mild hypoxia in our study sample: the maximum number of desaturation events was 11, representing a desaturation index (desaturation events per hour recording) of 1.4. Thus, our results on intermittent hypoxia and school impairment may not be applicable to children with more severe or frequent hypoxia during sleep.

Despite our findings on desaturation events, we did not find any relationship between desaturation clusters and school achievement. Desaturations of 4% or more were found to correlate to neuropsychologic disabilities in snoring adults (32), whereas desaturation clusters (a more specific type of 4% desaturations) seemed to be predictive of OSAHS in children (13). Desaturation clusters, however, have never been related to daytime symptoms in children. As they were found in 22% of subjects in the current study, it seems that they are common in primary school children and may, therefore, be considered rather benign in this age group. However, this has not yet been shown by any other study and thus remains purely speculative.

Several limitations of the current study must be considered. Our results may have been subject to biases inherent to surveys. Data on snoring were ascertained via parental questionnaire and not based on objective measures. Parental perception of nighttime symptoms like snoring depends on the presence of a family member within the bedroom of the child during the night and could be affected by personal, social, and cultural differences. Thus, snoring may tend to remain unrecognized by parents and, therefore, underestimated in surveys (under-reporting bias). If under-reporting bias was present, however, this would have led rather to an underestimation of the strength of the associations found. Conversely, for children with academic problems, parents may have been more likely to overreport snoring due to an increased awareness of any health problem (over-reporting bias). Despite these considerations and the fact that biases cannot be fully excluded, the robust and clear dose–effect relationship between habitual snoring and poor academic performance is consistent with the possibility that this breathing disorder may contribute to impaired school achievement in some children (16).

Our definition of poor academic performance is somewhat arbitrary; however, it roughly corresponds to the lowest quintile of a class. School grades only provide a rudimentary assessment of cognitive, behavioral, and learning capabilities, but the use of teacher ratings of academic performance was justified by past studies that have found relationships between biological risks and similar teacher ratings (7, 16). Teachers likely vary in their criteria used to assign grades. Some of the variability in academic performance will be obscured by this variability. We, therefore, adjusted for this potential influence in the logistic regression. Because teachers were unaware of the study goals at the time of the school report, grade scoring of each child enrolled in the study was, in any case, a truly unbiased process.

Although we adjusted for a number of variables, current findings could have resulted from the influence of an unstudied third variable. For example, behavioral disturbances like attention deficit or hyperactive behavior may likely have an impact on school achievement. Adjusting our results for these behavioral outcomes, however, likely would have resulted in overadjustment, reducing the apparent association between snoring and poor academic performance for reasons that are artificial rather than valid.

Due to our cross-sectional study design, we failed to determine whether snoring preceded poor academic performance. Establishing such a time sequence is a minimal criterion for demonstrating causality. Thus, the possibility that poor academic performance leads to snoring (or both are caused by an unstudied third variable) cannot be excluded. However, no ready explanation has been proposed for such a time sequence, and one experimental study of children treated for sleep-disordered breathing suggested that treatment improves school achievement (7).

All children surveyed were studied at home using pulse oximetry to identify intermittent hypoxia. Only a limited recording time during a single night was used, and a minimum of 5 hours of artifact-free recording was assumed sufficient for the study purpose. Although 90% of recordings comprised 7.7 hours or more, we may have failed to identify some children with intermittent hypoxia, leading to misclassification and lowering associated risks. This could also partially explain the weak association between intermittent hypoxia and poor academic performance in our study.

In conclusion, habitual snoring was common among these primary school children and was associated with poor academic performance in mathematics, science, and spelling. This relationship was only partially mediated via intermittent hypoxia because excluding children with desaturation events in an overnight study did not alter these results. The current findings, therefore, may be attributable to primary snoring and/or upper airway resistance syndrome rather than to OSAHS. This observation could have a public health impact, as it suggests that habitual snoring without intermittent hypoxia, up to now largely considered benign, may impair neurocognitive functioning in children and, thereby, academic success.

***Acknowledgment*:** The authors thank Dr. Ehrhardt (Department of Public Health, City Council, Hannover, Germany), Mrs. Martinsen (Supervisory School Authority, Hannover, Germany), Mr. Hegemann (District Government, Hannover, Germany), and the headmasters and teachers of the participating schools for their support and cooperation. The authors also thank Robert Downes (getemed AG; Teltow, Germany) and Volker von Einem (Department of Biomedical Engineering, Hannover Medical School, Hannover, Germany) for technical assistance, and Valerie Stebbens, BSc, for reviewing this manuscript. The authors thank the Hans Meineke Foundation, Hannover, Germany, for supporting this study, and they particularly wish to thank all the children and their parents for their patience and cooperation; they made this study possible.

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