PEDIATRICS®
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Pediatrics 2004;114;1041-1048
DOI: 10.1542/peds.2003-1145-L

Habitual Snoring, Intermittent Hypoxia, and Impaired Behavior in Primary School Children

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ABSTRACT. *Objectives.* **Sleep-disordered breathing is associated with impaired behavior and poor academic performance in children. We aimed to determine the extent of behavioral problems in snoring children, clarify the role of intermittent hypoxia, and test the reversibility of impaired behavior and poor academic performance.**

Methods. **In 1144 children, habitual snoring (HS; snoring frequently or always) and impaired behavior were assessed using parental questionnaires. Intermittent hypoxia (ie, presence of ≥5 arterial oxygen desaturations by ≥4% or ≥1 desaturation to ≤90%) was investigated with pulse oximetry. Poor academic performance (grade 4–6 on a 6-point scale in mathematics, science, or spelling) was based on the last school report. HS, impaired behavior, and academic performance were reevaluated after 1 year. Adjusted odds ratios (ORs) were calculated using unconditional logistic regression.**

Results. **HS was significantly associated with hyperactive (OR: 2.4) and inattentive behavior (OR: 4.0), daytime tiredness (OR: 7.1), and sleepiness (OR: 2.6–4.8). These associations were independent of intermittent hypoxia. HS was also significantly associated with bad conduct (OR: 2.8), emotional symptoms (OR: 5.5), and peer problems (OR: 9.7). At follow-up, hyperactive and inattentive behavior but not academic success had significantly improved in children in whom HS had ceased.**

Conclusions. **We suggest that impaired behavior is a key feature of HS independent of intermittent hypoxia and improves when HS ceases.** *Pediatrics* **2004;114:1041–1048;** ***snoring, hypoxia, child, child behavior disorders, attention deficit disorder with hyperactivity, hypersomnolence, learning disabilities.***

ABBREVIATIONS. SDB, sleep-disordered breathing; SDBQ, sleep-disordered breathing questionnaire; SDQ, Strengths and Difficulties Questionnaire.

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Accepted for publication Apr 6, 2004.
doi:10.1542/peds.2003-1145-L
Dr Urschitz received a travel grant in 2001 and a research support grant in 2004 from Masimo Corp (Irvine, CA).

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Sleep-disordered breathing (SDB) is suggested to affect daytime behavior and neurocognitive performance in children.[1] Signs of SDB (eg, loud and regular snoring, labored breathing during sleep) were found significantly more often among children with behavioral problems compared with control subjects.[2] Hyperactive and inattentive behavior was found to correlate with snoring in population-based[3–5] and hospital-based[6] cross-sectional studies, revealing a dose-effect gradient between snoring frequency and impaired behavior. These observations were extended such that some behavioral problems improved after treatment of the underlying SDB.[7–9]

There remains, however, uncertainty with respect to 1) a definitive causal relationship between SDB and impaired behavior,[10] 2) the underlying pathophysiologic mechanism(s),[11] 3) whether impaired behavior is also a consistent correlate of mild expressions of SDB,[7,12,13] 4) the role of impaired behavior as a mediating variable in the relationship between SDB and poor academic performance,[14] and 5) the range and expression(s) of impaired behavior in children with SDB.

One reason for the uncertainty concerning a causal relationship is the lack of longitudinal data showing that the occurrence of SDB precedes the onset of impaired behavior or that an improvement in behavior follows the termination of SDB. Establishing such a time sequence is a minimal criterion for demonstrating causality. To date, prospective cohort studies on SDB in childhood are lacking and follow-up data are sparse. Thus, the problem of definitively demonstrating a causal relationship remains unsolved.

Concerning the underlying mechanisms, intermittent hypoxia is thought to play an important role in the relationship between SDB and neurocognitive deficits in children.[11] Impaired attention and memory capacities, however, were also found in children who had only primary snoring, which is unlikely to result in intermittent hypoxia.[12,13] We recently found a significant association between habitual snoring and poor academic performance in the absence of moderate intermittent hypoxia (arterial oxygen saturation ≤90%).[14] Thus, even mild SDB without significant hypoxia may lead to neurocognitive deficits. Whether hypoxia is responsible for the behavioral problems found in children with SDB remains unclear.

We performed a population-based cross-sectional

cohort study on the prevalence of SDB and its association with poor academic performance and impaired behavior in primary school children.[14] We hypothesized that 1) impaired behavior is a significant correlate of SDB, 2) intermittent hypoxia does not play an important role in the relationship between SDB and impaired behavior, 3) impaired behavior plays a role as a mediating variable in the relationship between SDB and poor academic performance, and 4) impaired behavior and poor academic performance improve when SDB improves, thereby suggesting a causal relationship between SDB and related problems.

METHODS

Subjects

The recruitment strategy and basic characteristics of the study sample are described elsewhere.[14,15] In short, 27 of the 59 public primary schools located within the city limits of Hannover, Germany, were selected at random on the basis of an average socioeconomic status of parents. With the approval of the institutional review board and the regional directorate of education, all children who attended third-grade classes in these schools ($n = 1760$) were identified. The pupils received a letter of information explaining the study along with a consent form and a sleep-disordered breathing questionnaire (SDBQ). The pupils' parents were asked to fill in the SDBQ. Questionnaires were collected by the classroom teacher and picked up by a study crew member 1 to 2 weeks after the initial visit. Finally, 1144 (65.0%) children participated in the study. Comparisons to all eligible third graders ($n = 1760$) and the underlying source population of third graders ($n = 3809$) revealed good to excellent representativeness concerning gender distribution, socioeconomic status, academic performance, and diagnosis of asthma.[15]

SDBQ

Children were screened for symptoms of SDB by means of a widely used and validated questionnaire.[13,16–19] This questionnaire was translated into German, and questions were added concerning the child's demographic data (gender, age, height, weight, household smoking, and parental education) as well as daytime behavior (hyperactive-inattentive behavior and tiredness).[20] Race was not recorded, because the prevalence of nonwhites among participants was <5%. Snoring was investigated with the following question: "Does your child snore?" Responses were rated on a 4-point rating scale (never, occasionally, frequently, and always). Children were classified as habitual snorers when the answer was "frequently" or "always" and as nonsnorers when the answer was "never" or "occasionally." Hyperactive-inattentive behavior was investigated with the questions, "Is your child very restless, fidgety, or always in motion during daytime?" and, "Does your child have difficulties concentrating during daytime?" Daytime tiredness and sleepiness were investigated with the questions, "Is your child tired during daytime?" "Does your child fall asleep while watching television?" and, "Does your child fall asleep at school?" Answers were rated on a 5-point rating scale (never, rarely, occasionally, frequently, and almost always). Regarding the questions on hyperactive-inattentive behavior and daytime tiredness, the categories "frequently" and "almost always" were collapsed into "problem present"; the remaining categories were collapsed into "problem absent." Regarding the questions on daytime sleepiness, the categories "rarely," "occasionally," "frequently," and "almost always" were collapsed into "problem present," and "never" was categorized as "problem absent."

Nocturnal Home Pulse Oximetry

Detailed information on data acquisition and analysis and reference values are published elsewhere.[21] In short, children underwent nocturnal pulse oximetry recordings at home using an instrument (VitaGuard 300; getemed AG; Teltow, Germany) with a new-generation oximeter module (Masimo SET, version 3.0.2.1, 2–4 seconds moving averaging mode; Masimo Corp; Irvine, CA). A desaturation event was defined as a fall in arterial oxygen saturation to ≤90%. A desaturation cluster was defined as ≥5 desaturations by ≥4% occurring within 30 minutes.[22] Total and artifact-free recording time, as well as the number of desaturation events and clusters, were calculated using data analysis software (Matlab; MathSoft Inc, Cambridge, MA). A recording was considered sufficient when the artifact-free recording time was at least 5 hours. Desaturation events and clusters were confirmed visually to exclude spuriously low values that the software tool was not able to identify. Children were classified as experiencing intermittent hypoxia when at least 1 desaturation event or cluster was present. This definition was used because desaturation events and clusters were found to be predictive for obstructive sleep apnea.[22]

Academic Performance and School Behavior

With parental consent, last term's report form was obtained from the school archive. This form included written ratings on a 6-point scale (1 for "outstanding" and 6 for "failed") for mathematics, science, and spelling and ratings on a 4-point scale (1 for "outstanding" and 4 for "failed") for the child's ability to study and attitude toward peers. The above school subjects were chosen because ratings of these subjects had been shown to correlate with habitual snoring.[14] Poor academic performance was defined as grades 4 to 6 on the scale (approximately the lowest quintile grades) in at least 1 school subject.[14] Poor behavior at school was defined as grades 3 to 4 on the scale.

Follow-up

Approximately 1 year later (2002), snoring status and behavior of all habitual snorers among the study sample ($n = 114$) were reassessed using the SDBQ and the German version of the Strengths and Difficulties Questionnaire (SDQ).[23,24] The SDQ is a valid instrument for assessing hyperactive-inattentive behavior and other forms of behavioral problems in children.[24] It was used to confirm the high prevalence of hyperactive-inattentive behavior among habitual snorers and explore other kinds of impaired behavior in these children. Both questionnaires were sent to the children's homes by standard mail. In addition, the SDQ was sent to 114 gender- and school-matched nonsnoring control subjects (107 children had initially snored "never," and 7 had snored "occasionally"). On the basis of reference data from German children and adolescents, scores for each SDQ subscale were grouped either into a normal score range (problem absent) or into a borderline/abnormal score range (problem present).[25] Approximately 2 years later (2003), school performance during the school year 2002 was reevaluated in habitual snorers who participated in the 1-year follow-up ($n = 80$). For this evaluation, parents were contacted via telephone, and grades for mathematics, science, and spelling were obtained from the 2002 school report form. Poor academic performance again was defined as grade 4 or worse.

Statistics

All analyses were done with statistical software (SPSS, release 11.5 for Windows; SPSS, Chicago, IL). Descriptive statistics were used to summarize subject characteristics and questionnaire as well as pulse oximetry results. Comparisons between distributions were done using Pearson χ^2 and χ^2 test for trend where appropriate. Comparisons between paired dichotomized variables were done using McNemar test. For quantifying potential associations between snoring categories and behavioral problems, odds ratios and their 95% confidence intervals were calculated using unconditional logistic regression. Logistic models were adjusted for gender and age, and $P < .05$ was considered statistically significant.

RESULTS

Subject Characteristics and Behavioral Problems

Using the definitions given above, parent-reported hyperactive behavior, concentration deficits, and daytime tiredness were present in 25.8%, 16.6%, and 4.2%, respectively, of subjects. The corresponding values for falling asleep while watching television, falling asleep in school, and poor ratings in ability to study and attitude toward peers were 33.0%, 1.7%,

37.8%, and 24.3%, respectively. There were significant gender differences: hyperactivity (31.7% vs 20.2%; $P < .001$), concentration deficits (20.5% vs 12.9%; $P = .001$), poor ratings in ability to study (50.0% vs 27.4%; $P < .001$), and attitude toward peers (35.6% vs 14.1%; $P < .001$) were more prevalent in boys, whereas girls were more often reported to fall asleep while watching television (36.5% vs 30.5%; $P = .03$). No gender-related differences were found for daytime tiredness (4.5% vs 4.0%) and falling asleep in school (1.6% vs 1.8%).

Behavioral Problems and Snoring

Information on snoring was available for 1129 (98.7%) children. In total, 410 and 605 children were reported to snore "never" or "occasionally," and 114 were classified as habitual snorers according to the definitions given above. Analysis of questionnaires revealed an increasing prevalence of parent-reported behavioral problems with increasing snoring frequency, which was statistically significant for hyperactive behavior, concentration deficits, daytime tiredness, falling asleep while watching television, and falling asleep in school (Table 1). Logistic regression analysis revealed daytime tiredness as the behavioral problem most closely associated with habitual snoring (Table 1). In addition, children who snored occasionally also had a significantly increased risk for hyperactive behavior, concentration deficits, daytime tiredness, and falling asleep while watching television (Table 1).

Behavioral Problems and Intermittent Hypoxia

Detailed pulse oximetry recording results are presented elsewhere.[14] In short, 1115 recordings were performed, and 996 were considered sufficient for the study purpose. Of these, 130 (13.1%) recordings showed only desaturation clusters, 52 (5.2%) showed only desaturation events, and 93 (9.3%) showed both types of desaturation. Hence, 275 (27.5%) children had some kind of intermittent hypoxia. Concerning the total study sample, there was no statistically significant association between the presence of desaturation events, clusters, or both types of desaturation and any behavioral problem under study. Among the 114 habitual snorers, sufficient pulse oximetry recordings were available in 99. Of these, 11 (11.1%) had at least 1 desaturation cluster, 4 (4.0%) had desaturation events, and 14 (14.1%) had both types of desaturation; 70 (70.7%) had neither desaturation events nor clusters in their recording. Children with any desaturation event or cluster were grouped together ($n = 29$). Their behavior was compared with that of habitually snoring children who did not have desaturations ($n = 70$) and with nonsnorers with ($n = 84$) and without ($n = 268$) desaturations (Table 2). There were statistically significant differences between habitual snorers and nonsnorers but not between children with and without intermittent hypoxia. Impaired behavior was also a significant correlate of habitual snoring without any desaturation event or cluster (Table 2).

Behavioral Problems, Habitual Snoring, and Poor Academic Performance

Among the 114 habitual snorers, 59 (51.8%) performed poorly at school (ie, had grade 4 or worse in at least 1 of the 3 school subjects under study) in comparison with 129 (31.5%) of the 410 nonsnorers. Nonsnorers showed a significant correlation among concentration deficits, poor school behavior (inability to study and attitude toward peers), and poor academic performance, whereas hyperactive behavior, daytime tiredness, and sleepiness did not (Table 3). Concerning habitual snorers, all behavioral problems under study were significantly associated with poor academic performance, and odds ratios were up to 4 times higher. In children without poor academic performance, however, snoring did not significantly increase the risk for behavioral problems (Table 3).

Follow-up

Of the 114 habitual snorers, SDBQ follow-up results were available for (70.2%) 80 children. Mean time (standard deviation) between filling in the initial SDBQ and the follow-up SDBQ was 13.5 months (3.1). On average, follow-up participants had higher educated mothers compared with nonparticipants (prevalence of educational level 4: 16.3% vs 3.6%) but showed no difference in other basic characteristics (gender, age, body mass index, paternal education, and academic performance). At the 1-year follow-up, 39 (48.8%) of the former 114 habitual snorers still snored habitually, whereas 41 (51.2%) had stopped snoring habitually. On the basis of these results, children were classified as long-term habitual snorers ($n = 39$) and ex-habitual snorers ($n = 41$). At the

TABLE 1. Prevalence and Adjusted ORs Behavioral Problems Stratified by Frequency of Snoring in Study Participants ($N = 1129$)

Behavioral Problem	Snoring Frequency							
	Never ($N = 410$)		Occasionally ($N = 605$)			Habitually ($N = 114$)		
	N	%	*N*	%	OR (95% CI)	*N*	%	OR (95% CI)
Hyperactive behavior	82	20.2	169	28.3	**1.5 (1.1–2.1)**	42	37.2	**2.4 (1.5–3.9)**
Concentration deficits	45	11.1	108	18.0	**1.7 (1.2–2.5)**	36	31.9	**4.0 (2.4–6.6)**
Daytime tiredness	8	2.0	26	4.3	**2.2 (1.01–5.0)**	14	12.4	**7.1 (2.9–17.5)**
Falling asleep while watching television	100	24.8	217	36.2	**1.8 (1.3–2.4)**	52	46.8	**2.6 (1.7–4.1)**
Falling asleep at school	5	1.2	8	1.3	1.1 (0.4–3.4)	6	5.7	**4.8 (1.4–16.0)**
Poor rating in ability to study	145	36.1	228	38.8	1.0 (0.6–1.7)	52	46.8	1.0 (0.4–2.5)
Poor rating in attitude toward peers	100	24.9	146	25.0	0.9 (0.4–1.7)	30	27.0	2.1 (0.9–5.3)

OR indicates odds ratio; CI, confidence interval. ORs are adjusted for gender and age.
Reference category: snoring "never." Significant results are shown in bold typeface.

TABLE 2. Prevalence and Adjusted ORs for Behavioral Problems Stratified by Category of Snoring ($N = 451$)

Behavioral Problem	Snoring Category						
	Never Snoring Without Intermittent Hypoxia ($N = 268$)	Never Snoring With Intermittent Hypoxia ($N = 84$)		Habitual Snoring Without Intermittent Hypoxia ($N = 70$)		Habitual Snoring With Intermittent Hypoxia ($N = 29$)	
	n (%)	*n* (%)	OR (95% CI)	*n* (%)	OR (95% CI)	*n* (%)	OR (95% CI)
Hyperactive behavior	59 (22.2)	13 (15.7)	0.6 (0.3–1.2)	26 (37.7)	**2.3 (1.3–4.0)**	12 (41.4)	**2.4 (1.1–5.4)**
Concentration deficits	32 (12.0)	7 (8.4)	0.7 (0.3–1.6)	21 (30.4)	**3.3 (1.8–6.4)**	11 (37.9)	**4.8 (2.0–11.3)**
Daytime tiredness	7 (2.7)	0 (0.0)	X	8 (11.6)	**5.0 (1.7–14.5)**	3 (10.3)	**4.3 (1.03–17.6)**
Falling asleep while watching television	64 (24.3)	21 (25.0)	1.1 (0.6–1.9)	32 (47.1)	**2.8 (1.6–4.8)**	15 (53.6)	**3.8 (1.7–8.4)**
Falling asleep at school	4 (1.5)	0 (0.0)	X	3 (4.7)	3.1 (0.7–14.6)	1 (3.7)	2.5 (0.3–23.4)
Poor rating in ability to study	94 (35.7)	22 (26.2)	0.6 (0.3–1.01)	33 (49.3)	**2.2 (1.2–3.9)**	13 (44.8)	1.5 (0.7–3.4)
Poor rating in attitude toward peers	65 (24.7)	18 (21.4)	0.7 (0.4–1.4)	18 (26.9)	1.3 (0.7–2.6)	6 (20.7)	0.7 (0.3–2.0)

ORs are adjusted for gender and age.
Reference category: "never snoring without intermittent hypoxia." Significant results are shown in bold typeface.

TABLE 3. Prevalence and Adjusted ORs for Behavioral Problems Stratified by Category of Snoring ($N = 524$)

Behavioral Problem	Snoring Category						
	Never Snoring Without Poor Academic Performance ($N = 281$)	Never Snoring With Poor Academic Performance ($N = 129$)		Habitual Snoring Without Poor Academic Performance ($N = 55$)		Habitual Snoring With Poor Academic Performance ($N = 59$)	
	n (%)	*n* (%)	OR (95% CI)	*n* (%)	OR (95% CI)	*n* (%)	OR (95% CI)
Hyperactive behavior	48 (17.2)	34 (26.8)	1.6 (0.98–2.8)	13 (24.1)	1.5 (0.8–3.1)	29 (49.2)	**4.7 (2.5–8.6)**
Concentration deficits	21 (7.5)	24 (18.9)	**2.6 (1.3–4.9)**	8 (14.5)	2.2 (0.9–5.2)	28 (48.3)	**10.6 (5.3–21.2)**
Daytime tiredness	5 (1.8)	3 (2.4)	1.1 (0.2–4.8)	1 (1.9)	1.1 (0.1–9.5)	13 (22.0)	**13.8 (4.6–41.5)**
Falling asleep while watching television	64 (23.3)	36 (28.1)	1.2 (0.7–1.9)	18 (34.6)	1.8 (0.95–3.4)	34 (57.6)	**4.1 (2.3–7.5)**
Falling asleep at school	4 (1.4)	1 (0.8)	0.6 (0.1–5.2)	1 (2.0)	1.4 (0.1–12.5)	5 (9.1)	**7.1 (1.8–28.4)**
Poor rating in ability to study	61 (22.3)	84 (65.1)	**5.3 (3.3–8.7)**	12 (22.2)	1.1 (0.5–2.3)	40 (70.2)	**7.6 (3.9–14.9)**
Poor rating in attitude toward peers	47 (17.2)	53 (41.1)	**2.6 (1.5–4.3)**	8 (14.8)	0.9 (0.4–2.1)	22 (38.6)	**2.7 (1.4–5.3)**

ORs are adjusted for gender and age.
Reference category: "never snoring without poor academic performance." Significant results are shown in bold typeface.

initial assessment, there were no significant differences between both groups in the prevalence of behavioral problems, whereas there were such differences concerning hyperactive behavior and concentration deficits at follow-up (all $P < .05$). Compared with the initial assessment, the prevalence of all behavioral problems had decreased in the ex-habitual snoring group at follow-up, which was statistically significant for hyperactive behavior and concentration deficits, whereas there was no comparable decrease in the long-term habitual snoring group (Table 4). SDQ results were available for 41 ex-habitual snorers, 37 long-term habitual snorers (in total, 68.4% of all habitual snorers), and 80 control subjects. Although there was no association between the ex-habitual snoring status and behavioral problems, statistically significant relations were found between long-term habitual snoring and con-

TABLE 4. Prevalence of Behavioral Problems at the Initial Assessment and at 1 Year Follow-up Stratified by Category of Habitual Snoring ($N = 80$)

Behavioral Problem	Habitual Snoring Category									
	Ex-habitual Snoring ($N = 41$)					Long-Term Habitual Snoring ($N = 39$)				
	Initial Assessment		1-Year Follow-up		McNemar Test	Initial Assessment		1-Year Follow-up		McNemar test
	n	%	*n*	%	*P* Value	*n*	%	*n*	%	*P* Value
Hyperactive behavior	14	34.1	6	16.2	**.016**	15	39.5	14	41.2	1.0
Concentration deficits	11	26.8	4	11.1	**.016**	15	38.5	13	38.2	1.0
Daytime tiredness	4	10.0	1	2.8	.375	6	15.4	3	8.6	.688
Falling asleep while watching television	15	37.5	12	32.4	1.0	21	55.3	19	54.3	.727
Falling asleep at school	1	2.6	0	0.0	1.0	2	5.6	1	2.9	1.0

Significant results are shown in bold typeface.

TABLE 5. Prevalence and Adjusted ORs for Behavioral Problems at 1-Year Follow-up Stratified by Category of Snoring (N = 158)

Behavioral Problem	Definition	Snoring Category							
		Controls (N = 80)		Ex-habitual Snoring (N = 41)			Long-Term Habitual Snoring (N = 37)		
		n	%	n	%	OR (95% CI)	n	%	OR (95% CI)
Conduct problems	Score >3	13	16.3	7	17.1	1.3 (0.5–3.8)	11	29.7	**2.8 (1.03–7.7)**
Hyperactivity-inattention	Score >5	15	18.8	7	17.1	0.9 (0.3–2.7)	15	40.5	**4.2 (1.7–10.8)**
Emotional symptoms	Score >3	13	16.3	9	22.0	1.4 (0.5–3.9)	18	48.6	**5.5 (2.2–13.8)**
Peer problems	Score >3	4	5.0	4	9.8	2.9 (0.6–13.9)	10	27.0	**9.7 (2.4–39.1)**
Lack of prosocial behavior	Score <6	4	5.0	1	2.4	0.5 (0.05–4.8)	4	10.8	2.5 (0.5–13.0)
Total difficulties	Score >12	17	21.3	7	17.1	0.8 (0.3–2.2)	18	48.6	**4.3 (1.8–10.7)**

ORs are adjusted for gender and age.
Reference category: controls. Significant results are shown in bold typeface.

duct problems, hyperactivity-inattention, emotional symptoms, and peer problems (Table 5). The prevalence of lacking prosocial behaviors was twice as high among long-term habitual snorers than in control subjects, although this difference did not reach statistical significance (Table 5). Information on academic performance from the 2-year follow-up was available for 38 ex-habitual snorers and 31 long-term habitual snorers (in total, 60.5% of all habitual snorers). There was no statistically significant change in the prevalence of poor academic performance, neither in the long-term habitual snoring group nor in the ex-habitual snoring group (Table 6). In addition, academic performance was not significantly different between groups, neither in the initial nor in the follow-up assessment.

DISCUSSION

We found parent-reported behavioral problems such as hyperactive-inattentive behavior and daytime tiredness and sleepiness significantly associated with snoring, showing a clear dose-effect gradient. Moreover, impaired behavior was associated with habitual snoring in the absence of desaturation in an overnight study and was a key feature in habitually snoring children who performed poorly in school. A deeper investigation into the behavior of snoring children using standardized and validated methods brought up a wide range of behavioral problems spanning from emotional to social problems. Finally, we found a significant improvement in behavior among snoring children who had spontaneously stopped snoring.

Because of our population-based study design and the good overall representativeness to the source population, our findings may be generalized to other predominantly white populations. Other studies consistently noted a high prevalence of impaired behavior in children with habitual snoring or SDB.[3–6] A dose-effect relationship, ie, increasing odds for behavioral problems going along with the snoring frequency, has also been reported.[6] Our longitudinal observation on an improvement in behavior in former habitual snorers who had spontaneously stopped snoring, the documentation of a biological gradient,[6] and the reported improvement in behavior after treatment of SDB[8] add evidence that the relationship between SDB and behavioral problems may be causal rather than coincidental. However, it is assumed that for causality to be established, the temporal evolution of snoring and its consequences is to be demonstrated. This was impossible in this study and, as a matter of fact, is impossible in most epidemiologic studies except for large population-based prospective cohorts enrolled from birth.

One of the key features of SDB is inattentive behavior.[12] This impairment is thought to result in subsequent lower memory capacity and intelligence[12] and could be partly responsible for the poor academic performance found in children with SDB.[14,18] In our study, concentration deficits were significant correlates of poor academic performance in both snorers and nonsnorers, whereas daytime tiredness and sleepiness were not. Thus, an inability to concentrate may be the mediating variable for the relationship between SDB and poor academic performance.

Ten percent of children were habitual snorers, but only approximately half of these showed significant daytime consequences (poor academic performance and behavioral problems). Thus, 5% of primary school children may experience habitual snoring leading to significant daytime consequences and thus may be candidates for treatment of their under-

TABLE 6. Prevalence of Poor Academic Performance at the Initial Assessment and at 1-Year Follow-up Stratified by Category of Snoring (N = 69)

Poor Academic Performance	Habitual Snoring Category									
	Ex-habitual Snoring (N = 38)					Long-Term Habitual Snoring (N = 31)				
	Initial Assessment		1-Year Follow-up		McNemar Test	Initial Assessment		1-Year Follow-up		McNemar Test
	n	%	n	%	P Value	n	%	n	%	P Value
In mathematics	10	26.3	13	34.2	.508	10	32.3	13	41.9	.453
In science	8	21.1	11	28.9	.508	7	22.6	11	35.5	.125
In spelling	8	21.1	14	36.8	.109	9	29.0	12	38.7	.727

lying SDB. Conversely, half of the habitual snorers did not show poor academic performance, and these did not have a significant risk for impaired behavior. Differences in biological susceptibility or disease severity could be potential reasons for this finding. Additional effort is needed to develop objective screening measures that accurately distinguish between "malignant" habitual snoring (ie, snoring that leads to significant consequences) and "benign" habitual snoring or indicate which snoring child will benefit from treatment before significant consequences develop.

It is thought that sleep disruption, intermittent hypoxia, and/or hypercarbia are physiologic correlates of SDB responsible for adverse daytime symptoms such as hyperactivity and difficulties in maintaining attention. They are suspected to cause prefrontal cortical dysfunction and lead to impaired cognitive execution.[11] The precise role of each of these physiologic disturbances is not known, but intermittent hypoxia is a potential candidate. Intermittent hypoxia is a widely known independent contributor to general intellectual deficits[26] and reaction time[27] in adult SDB. In addition to sleep fragmentation, intermittent hypoxia is thought to provide a determinant for cognitive performance in memory, problem solving, and executive skills.[28] In animal models, intermittent hypoxia induces substantial increases in neuronal cell loss and adversely affects spatial memory tasks.[29] However, a large population-based study revealed snoring associated with daytime sleepiness independent of the presence of sleep apneas.[30] Thus, activation of the sympathetic nervous system rather than apnea-related hypoxia was suggested to correlate with daytime sleepiness.[30]

In children, data from large population-based cohort studies on the association among intermittent hypoxia, cognition, and behavior are lacking. We recently demonstrated an association between intermittent hypoxia and poor academic performance in mathematics.[14] The observations made in the present study suggest that intermittent hypoxia may not be an important cause of behavioral problems. This was also found by others, suggesting that snoring, even without apnea and what would be perceived as clinically relevant desaturation, is associated with neurobehavioral consequences.[12,13] Taking these results into account, intermittent hypoxia may play a role rather in "classic" neurocognitive deficits such as problem solving than in impaired behavior. Several elements within snoring could be the determinants of such morbidity. Snoring children may be differentially affected in their sleep architecture, potentially leading either to visually recognizable cortical arousals (respiratory event–related arousal) or to dynamic spectral changes in the electroencephalogram.[31] These indicators of sleep fragmentation could adversely affect neurocognitive function and behavior in children with SDB.

Less is known about behavioral problems in children with SDB. Although hyperactive-inattentive behavior and daytime sleepiness were reported repeatedly in pediatric SDB,[3–6,12] other difficulties in behavior have not been mentioned so far. We therefore performed a more detailed evaluation of behavior at follow-up using a brief screening questionnaire covering behaviors, emotions, and relationships. Our results with this standardized and validated tool support the finding that hyperactive-inattentive behavior is common among habitual snorers. Moreover, we found significant emotional symptoms, conduct, and peer problems in habitually snoring children. These findings extend our knowledge on the daily life of habitual snorers, who may have reduced quality of life (as a result of emotional impairments), social disintegration (as a result of peer problems), and impaired parent–child interaction (as a result of conduct problems). Moreover, our results for children who had stopped snoring habitually before follow-up suggest that normal behavior (or at least a significant improvement) can be achieved when habitual snoring ceases. However, even when improvement or normalization of behavior occurs, this does not obligatorily mean that the process is fully reversible to the complete extend of the damage induced by the disorder. In other words, reversibility may be only partial attributable to lack of knowledge concerning the potential ability of the subject.

In contrast to behavior, academic success showed no improvement on cessation of snoring. This nonresponding of academic performance to snoring cessation may have several potential explanations: 1) there may be no causal relationship between habitual snoring and academic performance; 2) there may be a causal relationship but the follow-up sample was too small or biased or the methods used were insufficient to detect subtle changes in academic performance; 3) snoring may not have ceased in children who were categorized as ex-snorers but was simply not recognized by their parents; 4) in contrast to impaired behavior, neurocognitive deficits may not have improved, suggesting a long-lasting effect of SDB on neurocognition[19]; and 5) children had improved their neurocognitive performance, but this was not sufficient to improve grades 1 year later. In fact, the prevalence of poor academic performance was consistently higher at follow-up in either snoring group. The school report of 2002, which was used to assess academic achievement at follow-up, was the final report of the 4 primary school grades. Different teachers' rating styles thus may have influenced and obscured results. Others have shown that grades significantly improve in first graders when an underlying SDB is treated.[18] Thus, a causal relationship can be assumed. We therefore suggest methodologic shortcomings as the most likely explanation for our finding, but additional studies involving objective assessments are needed to clarify this point.

Limitations

Some limitations of the current study have been discussed elsewhere.[14] In short, data on snoring and behavior were ascertained via parent questionnaires and not based on objective measures. Therefore, underreporting bias (eg, misperception of snoring) and overreporting bias (eg, increased awareness of behavioral problems in snoring children) could have occurred. Despite these considerations, the robust

and clear dose-effect association between snoring and impaired behavior is consistent with the possibility that this breathing disorder may contribute to impaired behavior in some children.[5,6]

The observed association of SDB with impaired behavior could reflect confounding by a variety of social and health factors.[10] Although we adjusted for important confounders, some residual confounding might have led to our findings. There is, however, increasing evidence that SDB is associated with behavioral problems, independent of other demographic and respiratory health variables.[5]

We did not find any association between intermittent hypoxia and impaired behavior in our study. Several methodologic issues should be considered in this relationship. 1) To identify intermittent hypoxia, children were studied at home using pulse oximetry. A limited recording time (>5 hours) during 1 single night was assumed to be sufficient for the study purpose, but we may have failed to identify some children with intermittent hypoxia, leading to misclassification bias and thus underestimating associated risks. 2) The study may have been underpowered to allow for a reliable assessment of the effect of intermittent hypoxia on behavior. After all, the cohort with habitual snoring and intermittent hypoxia included only 29 children. Regarding the distribution and variability in behavioral scales and academic performance, this may be an insufficient sample size. If, however, intermittent hypoxia has an impact on behavior, then this relationship is expected to be independent of snoring. We did not find more behavioral problems in children with intermittent hypoxia compared with those without, either in the total study sample or in subgroups of snorers and nonsnorers. Insufficient sample size thus may be an unlikely explanation. 3) The definition of intermittent hypoxia was somewhat arbitrary. It thus is possible that some children without intermittent hypoxia may have had sustained milder desaturations and shorter clusters such that snoring may be a better surrogate of functionally relevant intermittent hypoxia than the criteria used in this study to define intermittent hypoxia.

For the follow-up assessment, only a part of the original sample of exposed children (habitual snorers) was available. This could have introduced some bias. Because of migration, several families were lost to follow-up (migration bias). Parents of ex-habitual snorers who had improved their academic performance could have been less interested in participating in a follow-up study than parents of ex-habitual snorers who had not improved their academic success (selection bias). This could also partly explain why we did not find an improvement in academic performance after the cessation of snoring.

CONCLUSION

Habitual snoring was common among these primary school children and was associated with hyperactive and inattentive behavior and daytime tiredness and sleepiness. This association did not seem to be mediated via intermittent hypoxia. At a 1-year follow-up, half of the former habitual snorers still snored habitually and their behavior, in contrast to the children who had stopped snoring habitually, had not improved. In addition to hyperactive-inattentive behavior, habitual snorers showed more emotional symptoms and conduct and peer problems than control subjects. Considering its high prevalence and assuming a causal link to disturbed behavior, habitual snoring seems to be a substantial public health problem in school-aged children.

ACKNOWLEDGMENTS

Ms Urschitz-Duprat was supported by a research grant from the Hans Meineke Foundation (Hannover, Germany); oximeter sensors were provided by Masimo Corp (Irvine, CA).

We thank Dr Cornelia Ehrhardt (Department of Public Health, City Council, Hannover, Germany), Petra Martinsen (Supervisory School Authority, Hannover, Germany), Jens Hegemann (District Government, Hannover, Germany), and the headmasters and teachers of the participating schools for support and cooperation. Our thanks also go to Robert Downes (getemed AG, Teltow, Germany) and Volker von Einem (Department of Biomedical Engineering, Hannover Medical School, Hannover, Germany) for technical assistance. We also thank Nicole Ata for reviewing the manuscript and the Hans Meineke Foundation (Hannover, Germany) for supporting this study, and we particularly thank all of the children and their parents for patience and cooperation; they made this study possible.

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CYBERBULLIES

"The fight started at school, when some eighth-grade girls stole a pencil case filled with makeup that belonged to a new classmate, Amanda Marcuson, and she reported them. But it did not end there. As soon as Amanda got home, the instant messages started popping up on her computer screen. She was a tattletale and a liar, they said. Shaken, she typed back, 'You stole my stuff!' She was a 'stuck-up bitch,' came the instant response in the box on the screen, followed by a series of increasingly ugly epithets. . . . The episode reflects one of many ways that the technology lubricating the social lives of teenagers is amplifying standard adolescent cruelty. No longer confined to school grounds or daytime hours, 'cyberbullies' are pursuing their quarries into their own bedrooms. Tools like e-mail messages and Web logs enable the harassment to be both less obvious to adults and more publicly humiliating, as gossip, put-downs, and embarrassing pictures are circulated among a wide audience of peers with a few clicks."

Harmon A. *New York Times*. August 26, 2004

Noted by JFL, MD

Habitual Snoring, Intermittent Hypoxia, and Impaired Behavior in Primary School Children

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Pediatrics 2004;114;1041-1048
DOI: 10.1542/peds.2003-1145-L