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Sleep-Disordered Breathing and Verbal Skills in School-Aged Community Children

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Abstract

Sleep-disordered breathing (SDB) has been repeatedly associated with neurocognitive deficits in children. However, impairments in verbal skills have been inconsistently reported. The effects of SDB on verbal skills of 76 age-, gender, ethnicity, and maternal education matched groups of children with habitual snoring, but normal overnight sleep studies (HS), and children with significant SDB were compared to non-snoring healthy controls. A multi-method assessment of verbal abilities, and language neurodevelopment was chosen to unravel verbal skills. Preschoolers' difficulties in processing verbal instructions of increasing linguistic complexity, and school-aged children's reduced ability of verbal concepts provide evidence of SDB effects on verbal abilities. Although overall cognitive performances of SDB children remain in normative range, their problematic verbal skills may ultimately adversely affect academic performances or socio-emotional behaviors.

Keywords

obstructive sleep apnea; habitual snoring; language

INTRODUCTION

The spectrum of sleep-disordered breathing (SDB), a highly prevalent condition in children, ranges from habitual snoring in its mildest form (HS) to obstructive sleep apnea (OSA), with the latter being reportedly present in 2–3% of school-aged children. OSA is characterized by partial or total obstruction of the upper airway during sleep, leading to disruption of normal

ventilation and repeated arousals that result in sleep fragmentation and inefficient sleep. These events, either alone or in combination, have been shown to adversely affect neurocognitive development (Beebe, 2006; Emancipator, et al., 2006; Kaemingk, et al., 2003; Montgomery-Downs, Crabtree, & Gozal, 2005; Rhodes, et al., 1995), and academic performance (Bass, et al., 2004; Carvalho, et al., 2005; Gozal, 1998). Habitual snoring, or nighttime snoring at least 3 nights a week in the absence of gas exchange abnormalities or sleep disruption, has mean prevalence rates in young children of approximately 10% to 12% (Ali, 2000; Blunden, Lushington, Lorenzen, Martin, & Kennedy, 2005; Hultcrantz, Lofstrand-Tidestrom, & Ahlquist-Rastad, 1995; O'Brien, et al., 2003). Although HS was long considered as void of any deleterious consequences, there is now suggestive evidence supporting increased probability of cognitive deficits among HS compared to non-snoring controls (Blunden, Lushington, Kennedy, Martin, & Dawson, 2000; Blunden, et al., 2005; Kennedy, et al., 2004; O'Brien, Mervis, Holbrook, Bruner, Klaus, et al., 2004; O'Brien, Mervis, Holbrook, Bruner, Smith, et al., 2004).

The extent to which different neurocognitive domains are altered in children with HS versus OSA, remains however controversial. Although deficits have been reported in attention, concentration, memory, and verbal and nonverbal intelligence (a review: (Beebe, 2006), these findings have not been consistently identified across studies. In children, findings of deficits in sustained and selective attention, alertness, academic performance and emotional regulation have been clearly more robust than other functional domains, such that in their review of more than 15 published studies that assessed performance in pediatric SDB, findings pertaining to language were found to be either strongly present or conspicuously absent. Studies reviewed found that verbal *learning* was compromised in school-aged children with adenotonsillar hypertrophy compared to controls, and particularly in older school-aged children (Kurnatowski, Putynski, Lapienis, & Kowalska, 2006). Others (Beebe, et al., 2004; Gottlieb, et al., 2004) did not find significant differences in verbal *intelligence* in children with and without SDB symptoms, whereas (Owens, Spirito, Marcotte, McGuinn, & Berkelhammer, 2000) found significantly lower scores for children with moderate compared to mild OSA on verbal intelligence, but not in receptive vocabulary. Comparing first-graders with SDB to healthy controls, (O'Brien, Mervis, Holbrook, Bruner, Klaus, et al., 2004; O'Brien, Mervis, Holbrook, Bruner, Smith, et al., 2004) did not find significant differences in verbal *ability* (DAS) or in language *neurodevelopment* (NEPSY), but did find a tendency towards reduced phonological processing among those with SDB. Although others (Lewin, Rosen, England, & Dahl, 2002) similarly did not find significant differences in verbal ability (DAS) of children with OSA compared to controls, they did find a significant negative correlation between verbal ability and the respiratory disturbance index (RDI, or apnea-hypopnea index AHI). This is suggestive that the more sleep is disrupted by the breathing disorder, the more the level of language development will be affected in children. Finally, with respect to snoring children, lower verbal intelligence scores were found (Kennedy, et al., 2004), which concurs to our previous results suggestive of difficulties with language development, and verbal intelligence for HS children when compared to controls (O'Brien, Mervis, Holbrook, Bruner, Klaus, et al., 2004). While most emphasized between-group differences, Suratt and colleagues (Suratt, et al., 2007; Suratt, et al., 2006) looked at the predictability of impaired cognitive function, e.g. verbal intelligence, in a clinic sample of school-aged children, where parental report of snoring possibly predicted reduced verbal intelligence slightly more strongly than apnea-hypopnea index (AHI). The two verbal subtests applied were; Vocabulary, i.e., requiring the formulation and expression of a definition, and Similarities, i.e., indicative for verbal abstract reasoning, of the WISC, which is intriguing given that verbal knowledge is highly correlated with full-scale intelligence or cognitive functioning. Of similar interest, are the studies were 'snoring' was treated, indeed, although some primarily aimed at delineating benefit of treatment, e.g. in particular on medical and behavioral level, the overall comparison of language performance might presumably have been of a secondary interest (Friedman, et al., 2003; Harvey,

O'Callaghan, Wales, Harris, & Masters, 1999; Lewin, et al., 2002; Owens, et al., 2000). Hence, because some of the children in these studies met criteria for OSA, it is difficult to determine the impact of habitual snoring versus OSA on verbal skills in these samples. These studies however do provide suggestive evidence that snoring and AHI, among other variables, might potentially be associated with reduced language skills.

Of note, the most salient methodological limitations in many of the aforementioned studies included small sample sizes, sampling biases, i.e., clinical pre-/post treatment samples sometimes without control groups, and multicollinearity among possible predictors or confounders such as socio-economic status (Emancipator, et al., 2006). These could potentially lead to Type II and Type I errors being further accumulated in studies that merely focus on composite scores of ability or intelligence tests, and primarily rely on just one assessment method. This is however surprising since language is a well-studied function within the field of neuropsychology and specific language problems form a real threat to overall developmental progress, resulting in the availability of a variety of measures assessing components of a child's verbal skill. Sequentially language component comparisons might reveal a more characteristic performance pattern along the SDB spectrum. Therefore, we hypothesized that children with more severe SDB would be more likely to reveal a characteristic pattern of reduced verbal skills, when controlling for possible confounders. The aim of the present study was to examine differences in verbal skills between matched community recruited children who fulfilled polysomnographic criteria for OSA, HS, or non-snoring controls.

METHODS

Participants

Parents of children enrolled in the first through third grades in public school systems in Louisville, Kentucky, and surrounding areas completed a previously-validated sleep habits questionnaire (Gozal, 1998). Exclusionary criteria for participation in the study included chronic medical conditions, genetic or craniofacial syndromes, developmental delays, a current Individual Education Plan (IEP) at school, indicative of significant learning or other difficulties, current use of psychotropic medications, the presence of an acute infection, or a past adenotonsillectomy. Children who did not meet exclusionary criteria according to the questionnaire were invited to the sleep laboratory for overnight polysomnography followed by neurocognitive testing the next morning. Children were tested by a trained psychometrician (S.H., J.B.) in a quiet room without a parent present. Psychometricians were blind to the child's PSG results and to their group status. Protocols were double-scored by the psychometricians to ensure accuracy, with any disagreements in scoring resolved via discussion.

Measures

Multi-method assessment of Language—The neurocognitive assessment included subtests from the School-Age or Preschool Form of the Differential Ability Scales (DAS; (Elliott, 1990), the NEPSY (version 1, (Korkman, 1998), the Peabody Picture Vocabulary Test, 3rd edition (PPVT-III; (Dunn, 1997) and the Expressive Vocabulary Test (EVT; (Williams, 1997).

The DAS is a battery of cognitive tests designed to measure reasoning and conceptual *ability* in children. The Verbal Ability cluster reflects knowledge of verbal concepts and level of vocabulary development, and in schoolaged children it is also indicative of word retrieval from long-term memory. Individual subtests administered included *Word Definitions*, which measures knowledge of word meanings as demonstrated through spoken language or the ability to formulate definition of words (verbal fluency). *Similarities* measures verbal reasoning and knowledge where inductive reasoning ability or the ability to relate 3 words to superordinate

categories is necessary to earn credit. The ability score for each subtest is converted to a T score with a mean of 50 and a standard deviation (SD) of 10. The sum of the two subtests is then converted to yield a total standard score for Verbal Ability, with a mean of 100 and a SD of 15. For the Preschool version of the DAS, administered to younger children in the sample, the Verbal Ability standard score is derived from the *Verbal Comprehension* subtest, which measures receptive language, i.e., understanding of language or knowledge of prepositional and relational concepts. *Naming Vocabulary* subtest measures expressive language, i.e., the ability to attach verbal labels to pictures and retrieve them from long-term memory.

The NEPSY was designed to assess *neurocognitive development* across five functional domains, including language. Subtests administered include *Phonological Processing*, which assesses the capacity to identify words from segments and form an auditory gestalt. It measures the child's ability to phonological segment at the level of letter sounds and, the more complex word segments, reflecting phonological awareness. *Speeded Naming*, which assesses the ability to access and produce familiar words rapidly, with the total score incorporating time-to-completion or the speed, and the accuracy. *Comprehension of Instructions*, which assess the ability to process and respond to verbal instructions of increasing semantic and syntactic complexity, or receptive language comprehension. Subtests scores have a mean of 10 and an SD of 3, and are summed and converted to a Core Domain score for Language, which has a mean of 100 and a SD of 15.

The PPVT-III and EVT are *achievement* tests, and commonly administered in this order. The PPVT is a measure of receptive vocabulary by the use of a multiple-choice, nonverbal response format and the EVT is a measure of expressive vocabulary by the use of a labeling and a synonyms task; each yield a single score with a mean of 100 and a SD of 15. Additionally, testing starts according to entry levels (age or ability level), with the PPVT-III having a basal set established by one or no errors, and ceiling item set containing eight incorrect responses. The EVT proceeds until basal and ceiling, i.e., 'five and five' rule or five consecutive in/correct items, is established. These tests are co-normed allowing for comparisons of scores. Because the EVT is a single-word, expressive vocabulary test it allows assessing verbal skills relatively uncontaminated by more general deficits in expressive language, and further it might be useful, i.e., in contrast to the receptive language test such as PPVT-III, to evaluate word-finding problems. Indeed, the EVT measures the retrieval of a word from the lexical store whereas the PPVT-III represents the vocabulary knowledge. Noteworthy this receptive-expressive discrepancy may be more common in otherwise healthy children, limiting their specificity and sensitivity.

Therefore, and summarizing, our multi-method approach of language involves an *ability* test (DAS), a *neurodevelopmental* test (NEPSY) and two *achievement* tests (EVT and PPVT-III) and their confluent results may further help to unravel the SDB child's performance.

Night time polysomnography (NPSG)—A standard overnight multichannel polysomnographic evaluation was performed at the University of Louisville Pediatric Sleep Research laboratory. Children were studied for up to 12 hours in a quiet, darkened room with an ambient temperature of 24°C with a parent or guardian present. No drugs were used to induce sleep. The following parameters were measured: chest and abdominal wall movements assessed by inductance plethysmography, heart rate assessed by electrocardiography, and air flow monitored by sidestream end-tidal capnography, which also provided breath-by-breath assessments of end-tidal carbon dioxide levels (BCI SC-300; Menomonee Falls, WI), nasal pressure, and an oronasal thermistor. Arterial oxygen saturation (SpO₂) was assessed by pulse oximetry (Nellcor N 100; Nellcor Inc, Hayward, CA), with simultaneous recording of the pulse waveform. Bilateral electro-oculograms, 8 channels of the electroencephalogram, chin and anterior tibial electromyograms, and analog output from a body-position sensor (Braebon

Medical Corp, Ogdensburg, NY) were also monitored. All measures were digitized with a commercially available polysomnographic system (Stellate, Montreal, Canada). Tracheal sounds were monitored with a microphone sensor (Sleepmate, Midlothian, VA), and a digital, time-synchronized video recording was obtained.

Sleep architecture was assessed by standard techniques (Rechtschaffen, 1968). The proportion of time spent in each sleep stage was expressed as percentage of the total sleep time (TST). Awakenings were defined as sustained arousal lasting for ≥ 15 seconds. The apnea index was defined as the number of episodes of apnea per hour of TST. Central, obstructive, and mixed apneic events were counted. Obstructive apnea was defined as the absence of airflow ($>80\%$ reduction) with continued chest wall and abdominal movements for the duration of at least 2 breaths (American Thoracic Society, 1996; Montgomery-Downs, O'Brien, Gulliver, & Gozal, 2006). Hypopnea was defined as a decrease in nasal flow of $\geq 50\%$ with a corresponding decrease in SaO_2 of $\geq 4\%$ and/or an arousal (American Thoracic Society, 1996; Montgomery-Downs, et al., 2006). The respiratory disturbance index (RDI) was defined as the number of episodes of apnea and hypopnea per hour of TST. The mean SaO_2 , as measured by pulse oximetry in the presence of a pulse waveform signal void-of-motion artifact, and the SaO_2 nadir were recorded. Arousals were expressed as the total number of arousals per hour of sleep time (arousal index), and were defined as recommended by the (American Sleep Disorders Association Task Force, 1992) and included respiratory-related (occurring immediately following an apnea, hypopnea, or snore), technician-induced, and spontaneous arousals. The Respiratory Arousal Index (RAI) was defined as the number of respiratory arousals per hours of TST.

BMI Z score – obesity measurement—Height and weight were recorded for each child. Body mass index z score was calculated using an online BMI z score calculator provided by the CDC (<http://www.cdc.gov/epiinfo/>). Children with BMI z score values greater than 1.57 were considered as obese.

PROCEDURES

Study Recruitment and Participant Information

In defining SDB, a previously reported composite score incorporating RDI, RAI, and oxyhemoglobin desaturations (SaO_2 nadir) was utilized (O'Brien, Mervis, Holbrook, Bruner, Smith, et al., 2004), such that children were assigned composite scores according to the severity of their disturbance across these three measures. Children with a composite score of ≥ 4 were identified as having OSA. Controls and HS subjects had a composite score of ≤ 3 . Children were identified as “snorers” if parents reported snoring frequently (3–4 times per week) or almost always (>4 times per week) and “non-snorers” if parents reported snoring never or rarely (once per week). If parental report was not available ($n=39$) or if a parent reported occasional (twice per week) snoring ($n=123$), the presence of snoring was verified from the polysomnographic record. Children were thus classified as non-snoring controls ($n=76$), HS ($n=76$), and OSA ($n=76$). Children included in the current analysis were identified and matched from an initial cohort of 820 participants. Of these children, 101 were found to meet criteria for OSA. Due to the matching criteria however, only 76 children could be matched to both HS and non-snoring controls. Each child with OSA was matched to one child with HS and one control subject for all of the following, without exception: maternal educational attainment (college graduate and higher or high school or lower), ethnicity (Caucasian and African American), age (within one year) and gender. When a child met criteria to be matched with more than one other child, the following approach was utilized to obtain the closest match: 1) closest in age (year and month) and 2) closest in date of testing. Prior to matching, children with any scores that were not within 3 standard deviations of the mean ($n=3$) (Beebe, et al.,

2004) were excluded. Because certain measures were added to the neurocognitive battery later in the course of data collection, sample sizes are lower for the PPVT-III (n=140) and EVT (n=139). Sample sizes for the DAS Word Definitions (n=139) and DAS Similarities (n=139) subtests are lower because, in the case of younger children in the sample, the Preschool Version (n=89) was administered, in which the DAS Verbal Ability score is derived from different subtests.

The final sample (n=228) was 46% female and 37% African-American, with a mean age of 6.68 (SD=.59; control: 6.72±.53, HS: 6.67±.55, OSA: 6.64±.68) with 31.9% of the sample was obese ($\chi^2(2,191)=14.47$, $p=.001$); control: 22.4%, HS: 25%, OSA:51.8%). Regarding maternal educational attainment the sample consisted of 66% of the mothers were college graduate and higher, and 44% high school or lower.

Data Analyses and Statistical procedures

Descriptive statistics are presented as means and standard deviations unless otherwise indicated. Differences between groups were assessed using Chi-square analyses, one-way ANOVA and one-way Analysis of Covariance (ANCOVA), with Tukey HSD post-hoc (printed when significant). We controlled for the global composite ability (GCA, i.e., similar to IQ) because substantial significant ($p<0.05$) correlations were found between GCA and verbal ability (DAS preschooler: 0.75 and schoolaged; 0.79), with NEPSY language (0.63), with PPVT-III (0.66) and EVT (0.74). All analyses were conducted using Statistica (StatSoft, Inc. (2008). STATISTICA (data analysis software system), version 8.0. www.statsoft.com.). Statistical significance was set at $p<.05$. Cohen's d effect sizes were calculated to underscore the clinical profile potentially characteristic of the spectrum; with $.2<d<.5$ denoting a small effect, $.5<d<.8$ denoting a medium effect, and $d>.8$ denoting a large effect (Cohen, 1988). If groups were significantly different in verbal skills, and because the sample was matched, a posteriori analyses with respect to gender and ethnicity differences were then pursued.

RESULTS

For the polysomnographic variables (Table 1), there were no significant differences between the three groups for total sleep time, sleep efficiency, sleep latency, REM latency, spontaneous arousal index, and percentage of total sleep time for Non Rapid Eye Movement (NREM) Stage 1, Stage 2, Stages 3 + 4, and REM sleep. The OSA group had a significantly higher respiratory arousal index, respiratory disturbance index, and obstructive apnea index compared to each of the other groups, as well as a significantly lower SpO₂ nadir and mean SpO₂. Sleep was comparable between the non-snoring controls and HS. As such, breathing during sleep was clearly compromised in the OSA group.

Table 2 shows the results on the verbal skills multi-method assessment of the control, HS, and OSA child. Because of the significant unequal distribution of GCA in the preschoolers ($\chi^2(2,89)=8.87$, $p=.012$), we controlled for its interaction effect, i.e. GCA and condition in this age cluster, which was not necessary for school-aged; ($\chi^2(2,139)=0.33$, $p=.849$), i.e. hence here only the covariate GCA was accounted for, resulting in a special verbal skill pattern in preschoolers and school-aged children.

Preschoolers verbal ability as assessed with the DAS was comparable among groups, whereas *neurodevelopmentally* the OSA children showed significant lower receptive language comprehension than controls (Comprehension of Instructions). A *posteriori* analysis revealed that this observation was present in males [$F(2,39)=5.99$, $p=.005$; control: 10.62±2.63, HS: 10.07±2.63, OSA:8.25±3.47 with Cohen's d: (1) vs. (2)=.21, (1) vs.(3)=.76 and (2) vs. (3)=.59] and White Non-Hispanics [$F(2,46)=6.39$, $p=.003$, Tukey Post Hoc 1>3 ($p=.013$); control: 11.87±1.64, HS:11±2.68, OSA:9.5±2.87 with Cohen's d: (1) vs. (2)=.39, (1) vs.(3)=1.02 and

(2) vs. (3)=.54]. A supplemental analysis of the Speeded Naming subtest was further suggestive of a slower, and especially less accurate automaticity of sound-symbol association or processing problem (note the variability in the OSA group). Hence error profile analysis as well as qualitative analysis should be able to reveal better the underlying deficits, since the confluence of accuracy and time reflected in the Speeded Naming score was not different between the groups.

Results for school-aged children denoted an *ability* problem, though overall, HS as well as OSA exhibited lowered, albeit within normal range, levels of vocabulary development. A posteriori analyses indicated that this was apparent in females [$F(2,53)=4.03$, $p=.024$, Tukey Post Hoc $1>2$ ($p=.035$) and $1>3$ ($p=.001$); control: 103.24 ± 14.09 , HS: 95.95 ± 12.34 , OSA: 91.40 ± 11.53 with Cohen's d : (1) vs. (2)=.55, (1) vs.(3)=.91 and (2) vs. (3)=.38] and White Non-Hispanics [$F(2,83)=4.52$, $p=.014$, Tukey Post Hoc $1>2$ ($p=.012$), $1>3$ ($p=.0001$), $2>3$ ($p=.007$); control: 106.33 ± 16.55 , HS: 98.72 ± 15.02 , OSA: 90.08 ± 13.09 with Cohen's d : (1) vs. (2)=.48, (1) vs.(3)=1.08 and (2) vs. (3)=.61]. This reduced verbal ability became further apparent in the Word Definitions subtest, reflecting also crystallized mental ability, and especially for the OSA children when compared to controls. A posteriori analyses indicated that this pattern was clearly valid for females [$F(2,53)=3.55$, $p=.036$, Tukey Post Hoc $1>3$ ($p=.002$); control: 53.19 ± 7.72 , HS: 49 ± 8.72 , OSA: 45.13 ± 10.31 with Cohen's d : (1) vs. (2)=.51, (1) vs.(3)=.92 and (2) vs. (3)=.42] and White Non-Hispanics [$F(2,83)=3.8$, $p=.026$, Tukey Post Hoc $1>2$ ($p=.022$), $1>3$ ($p=.0001$), $2>3$ ($p=.035$); control: 55.94 ± 9.16 , HS: 50.83 ± 8.56 , OSA: 45.72 ± 12.18 with Cohen's d : (1) vs. (2)=.58, (1) vs.(3)=0.98 and (2) vs. (3)=.50]. Although performances on PPVT-III and EVT were not characteristic for any group, and a typical mean comparison score was not significantly associated to a group, the minus sign for the control group could be potentially indicative of their verbal fluency.

DISCUSSION

This carefully matched study is indicative of a complex verbal skill profile in the SDB child, with preschool age children with SDB showing difficulties in processing information with increasing linguistic complexity, whereas school-aged children presenting with reduced vocabulary knowledge or ability, and this effect of SDB was particularly prominent in the OSA group. This finding may potentially support the hypothesis of a longitudinal adverse effect of sleep-disordered breathing. Furthermore, the language-learning disability as shown here might adversely affect school achievement, since the academic setting is highly verbal, and consequently language problems form a real threat for the orderly overall developmental progress of children with sleep-disordered breathing.

Before we discuss the potential significance and implications of current findings, several methodological issues deserve comment. First, our cohorts were derived from the community, and did not originate from clinical referral populations, thereby annulling any potential sample bias. It is possible that the latter may be more vulnerable to OSA-induced morbidity, such that differences among the three groups may have been further enhanced if we had selected clinically symptomatic children. Second, the matching criteria used here led to exclusion of a large number of children, such as to achieve multiple confounder parity across the three groups. These strict precautionary measures confer, in our opinion, enhanced validity to the occurrence of any differences emerging from the analysis, particularly considering the inclusion of maternal education as a proxy for SES. Furthermore, the cohort sizes reported herein are substantial, and further subdivision in age clusters were consequently possible, thereby further enhancing the global implications of the verbal skills deficits occurring among children with SDB in general, and more particularly among those with OSA. A potential limitation of this study is that it focuses on merely language skills, and does not embed results in other developmental domains, and even behavioral aspects such as stranger anxiety, shyness further

affecting generative verbal fluency. Furthermore, the lack of scholastic achievement such as reading and spelling performance could have enhanced clinical interpretation. Finally, the statistical analyses conducted, in combination with the decision on group assignment being determined using a system of composite scores incorporating multiple measures of SDB, do not allow predictive associations among sleep and verbal skills.

In the present multi-method study of verbal skills, differences between the groups were found for certain components such skills. Although the ability to follow verbal instructions seemed to be age-adequate, and only moderately different from the otherwise healthy children, the preschoolers with SDB showed significantly reduced performance in subcomponents of receptive language. Indeed, the OSA child exhibited problems with processing of verbal messages that become increasingly semantically and syntactically complex. Error profile as well as qualitative analysis may certainly expose if the deficit is rooted in problems such as reduced auditory acuity, auditory-verbal processing, attentional or rather memory issues with recency or primacy effects. Likewise, problems with understanding spatial conceptual terms, and negation, temporal and sequential aspect of the instructions should all be considered as well. Given that language processing may be hierarchical in nature (Binder, et al., 1994), the extent to which temporal processing deficits are the main impairment underlying language disorders in children with SDB remains a topic of discussion (Stark, 1988). While pre-schoolers linguistic performance showed evidence of difficulties in processing verbal instructions of increasing complexity, school-aged children exhibited reduced ability of verbal concepts, which might be construed as a longitudinal effect. The significantly reduced performance found on the Word Definitions subtest of the DAS may be indicative of verbal intelligence problems, and because PPVT-III and EVT performances, which represent receptive and expressive language achievement of the child, fell within normal ranges, an impairment in verbal concept knowledge or inefficient retrieval process from long-term memory can be postulated, with the problem being potentially more pronounced in girls and among White Non-Hispanics. Therefore, school-aged SDB children would be expected to struggle with verbal concepts or have reduced verbal abilities.

When considering differences between the groups, and specifically HS and OSA, our results indicate a more disturbed profile among the children with more prominent respiratory disturbance during sleep. As such, our findings using multi-methodological approaches are aligned with the diversity of findings previously published in sleep literature, and in particular emphasize the importance of age (and potentially also intelligence) when comparing linguistic skills along the spectrum, since both (i.e., method and age) may have been possible confounders among the various studies.

Important steps for improved understanding of the mechanisms involved in verbal skills deficits in SDB will require elucidation of determinants of susceptibility. Indeed, factors such as individual genetic susceptibility and environmental lifestyle and nutritional factors have been proposed as potential moderators of end-organ injury (Goldbart, et al., 2006; Gozal & Kheirandish, 2006). In fact, some have (Ziliotto, et al., 2006) found auditory processing deficits on two tasks in children with OSA compared to controls, suggesting that auditory processing difficulties could play a role in the development of verbal deficits in some children with OSA. Variances in the magnitude of systemic inflammation have also been recently identified as playing a role in cognitive deficits associated with OSA (Gozal, Crabtree, Sans Capdevila, Witcher, & Kheirandish-Gozal, 2007; Gozal & Kheirandish, 2006). In addition, neuroimaging studies may further elucidate the location and extent of lesions associated with verbal deficits in the context of pediatric OSA (Halbower, et al., 2006).

In summary, this study demonstrates impairments in verbal skills associated with OSA in children and, to a lesser extent, in habitual snoring. The evidence of language impairments in

children with SDB further supports the concept that the first hit may be in linguistic processing, which may subsequently evolve into reduced verbal ability. Thus, findings of reduced verbal competence in school-aged children may reflect more extensive scholastic and/or behavioral difficulties, and should warrant evaluation and nighttime screening.

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TABLE 1
Night Time Polysomnography Among 228 Matched Children (Means, Standard Deviations and Percentages)

	Non-Snoring Controls (1)	Habitual Snoring (2)	Obstructive Sleep Apnea (3)	ANOVA	p-value	Tukey HSD Post Hoc
TST (min)	476.11 (35.27)	486.37 (37.86)	480.68 (42.98)	F(2,225)=1.33	p=.266	NS
Sleep efficiency (%)	90.66 (6.23)	90.39 (8.71)	91.10 (7.21)	F(2,225)=1.73	p=.841	NS
Sleep latency (min)	21.85 (22.23)	17.98 (16.85)	15.87 (14.97)	F(2,225)=2.09	p=.120	NS
REM latency (min)	142.09 (56.60)	140.18 (57.13)	154.61 (65.67)	F(2,225)=1.3	p=.275	NS
Stage 1 (% TST)	6.07 (4.58)	8.01 (8.13)	8.04 (6.68)	F(2,225)=2.19	p=.114	NS
Stage 2 (% TST)	45.94 (8.40)	45.37 (7.39)	44.21 (7.70)	F(2,225)=.948	p=.389	NS
Stage 3+4 (% TST)	25.90 (8.29)	25.89 (6.68)	27.82 (29.84)	F(2,225)=.282	p=.755	NS
REM Sleep (% TST)	21.15 (4.94)	21.30 (8.09)	22.88 (16.72)	F(2,225)=.569	p=.567	NS
SAI (%/hrTST)	7.26 (3.44)	7.42 (3.62)	6.22 (4.69)	F(2,225)=2.06	p=.129	NS
RAI (%/hrTST)	.53 (.78)	1.66 (3.48)	7.26 (5.00)	F(2,225)=78.51	p=.000	1>3 (p=.000) 2>3 (p=.000)
RDI (%/hrTST)	.92 (1.14)	1.09 (1.32)	9.92 (9.99)	F(2,225)=58.77	p=.000	1>3 (p=.000) 2>3 (p=.000)
OAI (%/hrTST)	.08 (.20)	.20 (.51)	1.85 (2.66)	F(2,222)=29.56	p=.000	1>3 (p=.000) 2>3 (p=.000)
SpO₂ Nadir (%)	92.67 (3.92)	92.20 (2.97)	82.62 (8.42)	F(2,221)=75.55	p=.000	1>3 (p=.000) 2>3 (p=.000)
Mean SpO₂ (%)	97.50 (1.16)	97.52 (1.11)	95.87 (4.38)	F(2,225)=9.32	p=.000	1>3 (p=.001) 2>3 (p=.001)

Note. Standard deviations presented in parentheses. NS=non significant; TST = total sleep time; REM – rapid eye movement; SAI = spontaneous arousal index; RAI = respiratory arousal index; RDI = respiratory disturbance index; OAI – obstructive apnea index; SpO₂ – oxygen saturation measured by pulse oximetry

TABLE 2

Language Performance Among 228 Matched Children (Means, Standard Deviations and Effect Sizes)

	Non-Snoring Controls (1)		Habitual Snoring (2)	Obstructive Sleep Apnea (3)	ANCOVA	p-value	Tukey HSD Post Hoc	Cohen's d			
									(1) vs. (2)	(2) vs. (3)	(1) vs. (3)
Preschoolers											
DAS Verbal Ability	98.29 (12.43)	98.83 (11.07)	92.85 (10.68)	F(2,84)=0.042	p=.959			-0.05	0.55	0.48	
Verbal comprehension	46.58 (9.03)	45.10 (6.92)	41.97 (7.59)	F(2,82)=0.290	p=.749			0.19	0.43	0.56	
Naming vocabulary	51.88 (7.80)	53.45 (8.99)	49.88 (8.88)	F(2,82)=0.511	p=.602			-0.18	0.40	0.24	
NEPSY Language	99.67 (15.86)	98.86 (15.91)	88.91 (15.60)	F(2,84)=0.723	p=.488			0.05	0.63	0.68	
Phonological Processing	10.19 (3.19)	10.14 (3.35)	7.73 (3.73)	F(2,84)=6.817	p=.575			0.01	0.68	0.71	
Spelled Naming	8.67 (2.97)	9 (3.74)	7.79 (4.14)	F(2,84)=1.847	p=.164			-0.10	0.31	0.24	
Time (max. 5 min)	2:27 (0:53)	2:53 (1:06)	2:44 (1:12)	F(2,81)=2.999	p=.055			-0.09	-0.17	-0.27	
Accuracy (max. 60)	56.88 (3.06)	57.03 (4.97)	52.06 (12.85)	F(2,80)=4.636	p=.012	NS		-0.04	0.55	0.57	
Comprehension of Instructions	10.93 (2.59)	10.28 (2.64)	9.00 (3.25)	F(2,84)=4.013	p=.022	1>3 (p=.026)		0.25	0.43	0.65	
Schooled											
DAS Verbal Ability	101.86 (16.89)	95.89 (14.19)	90.27 (12.25)	F(2,132)=4.255	p=.016	1>2 (p=.004) 2>3 (p=.012) 1>3 (p=.000)		0.38	0.42	0.78	
Word Definitions	52.78 (10.57)	48.85 (8.44)	45.30 (10.81)	F(2,132)=3.361	p=.038	1>3 (p=.002)		0.41	0.37	0.70	
Similarities	50.02 (11.24)	46.87 (10.53)	43.62 (6.04)	F(2,132)=1.191	p=.152			0.29	0.38	0.72	
NEPSY Language	96.98 (17.61)	97.19 (19.15)	94.11 (17.29)	F(2,127)=0.685	p=.506			-0.02	0.18	0.16	
Phonological Processing	9.12 (3.91)	9.62 (3.88)	8.25 (4.12)	F(2,132)=0.931	p=.397			-0.13	0.22	0.34	
Spelled Naming	8.90 (3.89)	9.11 (3.43)	9.08 (3.81)	F(2,127)=1.409	p=.248			-0.06	0.01	-0.05	
Time (max. 5 min)	2:07 (0:50)	1:52 (0:44)	2:02 (0:48)	F(2,125)=1.447	p=.239			0.30	-0.21	0.09	
Accuracy (max. 60)	55.7 (6.7)	55.2 (6.6)	56.2 (5.63)	F(2,215)=0.984	p=.376			0.08	-0.08	-0.16	
Comprehension of Instructions	10.35 (2.92)	9.79 (2.61)	9.05 (2.84)	F(2,132)=0.400	p=.672			0.20	0.27	0.45	
PPVT-III [†] Receptive Vocabulary	99.51 (15.90)	95.87 (12.93)	93.56 (13.57)	F(2,131)=0.321	p=.726			0.25	0.17	0.40	
EVT [†] Expressive Vocabulary	100.65 (14.85)	94.34 (13.62)	91.72 (13.37)	F(2,132)=2.603	p=.078			0.44	0.19	0.63	
PPVT-III & EVT comparison score [§]	-2.83 (17.56)	2.71 (16.26)	2.06 (15.96)	F(2,51)=0.490	p=.615			-0.33	0.04	-0.29	

Note. Standard deviations presented in parentheses. NS= not significant; DAS = Differential Abilities Scale; PPVT-III = Peabody Picture Vocabulary Test, 3rd edition; EVT = Expressive Vocabulary Test

[†] was not administered to preschoolers
[§] only when score was significantly different