Association Between Sleep Disordered Breathing and Behavior in School-Aged Children: The Tucson Children's Assessment of Sleep Apnea Study

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Abstract: Study Objectives: This study analyzed the association between the Respiratory Disturbance Index (RDI) and two behavior measures, the Conners' Parent Rating Scale (CPRS-R) and the Child Behavior Checklist (CBCL) in school-aged children to determine whether there is an optimal threshold of Sleep-disordered Breathing (SDB) associated with increased risk of behavior problems.

Methods: The Tucson Children's Assessment of Sleep Apnea Study (TuCASA) is an observational cohort study of 6-11 year old Caucasian and Hispanic children designed to assess the anatomic, physiologic and neurocognitive correlates of SDB. 403 children with both polysomnography (PSG) and behavioral data were included in this analysis. Three definitions of SDB were used: RDI independent of oxygen desaturation (RDI0), RDI with 2% oxygen desaturation (RDI2) and RDI with 3% oxygen desaturation (RDI3). T-scored behavioral data were dichotomized at a cutoff point of 65, a score indicative of moderate to severe clinical impairment. Logistic regression was used to access the risk associated with SDB.

Results: The analyses conducted using three different definitions of RDI suggest that the likelihood of having a clinically significant CPRS-R or CBCL subscale score was not necessarily progressive or linear across RDI categories. Cutoff points and prevalences for each definition of RDI proposed to be indicators of clinically significant SDB were RDI0 $\geq$ 7 (19.38%), RDI2 $\geq$ 2 (29.38%) and RDI3 $\geq$0.5 (23.96%) events per hour of sleep. Behaviors such as CPRS oppositional, social problems, psychosomatic and CBCL somatic complaints, social problems and aggressive behaviors were found to be significantly associated with SDB.

Conclusions: This analysis found an increased risk of behavior problems such as somatic complaints, oppositional or aggressive behaviors and social problems associated with sleep-disordered breathing in school-aged children. RDI cut points for three definitions of SDB are proposed: 7 for RDI0, 2 for RDI2, and 0.5 for RDI3 respectively.

Keywords: Sleep disordered breathing, children, behavior problems.

INTRODUCTION

Sleep disordered breathing (SDB) is a condition in which breathing during sleep is reduced for brief periods of time. Sleep apnea, defined as complete cessation of breathing, is the extreme form of SDB. SDB has been estimated to be present in 2-3% of the pediatric population [1]. SDB is acknowledged as an important cause of morbidity in children, with behavior and neurocognitive abnormalities occurring more commonly in children with SDB than in those without SDB [2-4]. Treatment for SDB can result in significant improvement in behavior and cognitive performance [5-7].

Recent research has suggested that children with SDB are at increased risk for behavior and cognitive abnormalities. A wide range of behavior problems has been associated with SDB including somatic complaints, aggression, oppositional behavior, anxiety, depression and hyperactivity [8-14]. However, not all studies have identified behavior problems as being related to SDB [15, 16]. Methodological issues may provide one explanation for this lack of consistency in findings pertaining to SDB and behavior (reviewed in [4]). Early studies did not utilize standardized behavior measures [17, 18]. Some studies have used only parent report for sleep and breathing problems [6, 17]. Not all have used polysomnograms (PSGs) together with standardized behavior measures [10, 19]. Moreover, most of the research has been done on clinical samples [6, 12, 20]; relatively few studies have examined these relationships in a population sample. The Respiratory Disturbance Index (RDI) which is the number of SDB events per hour of sleep, is the most common metric used to identify the occurrence and severity of SDB. However, the threshold for defining the presence of SDB has not been established for children.

The Tucson Children's Assessment of Sleep Apnea Study, TuCASA, is a prospective cohort study of sleep apnea and its effect on preadolescent children sampled from the general population. In this paper we analyze the association between the RDI and 2 behavior measures, the Conners' Parent Rating Scale (CPRS-R) and the Child's Behavior Checklist (CBCL), to determine whether there is an optimal

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threshold of SDB associated with an increased likelihood to experience abnormal behavioral outcomes.

METHODS

Subjects

The design of the TuCASA study specified recruitment of Hispanic and Caucasian children aged 6 through 11 years old to undergo unattended home PSG with anthropometric measurements, to complete a pediatric sleep habits questionnaire, and to perform a neurocognitive and behavior assessment. Subjects were recruited by eliciting cooperation from 19 elementary schools in the Tucson Unified School District, a very large school district with a population representative of children in southern Arizona. A detailed description of recruitment procedures has been previously published [21]. Briefly, parents were asked to complete a 1-page, 13-item survey designed to assess the severity of obstructive sleep apnea syndrome (OSAS) related symptoms in children. It was sent home with all children in a "notes home" folder. At the time the survey was completed, parents were given the opportunity to provide their contact information if they would allow study personnel to call for further participation. Children were excluded from the study if they had a history of asthma, OSAS, tonsillectomy, other chronic respiratory problems, or mental retardation. The Tucson Unified School District (TUSD) and the University of Arizona Institutional Review Boards approved the study protocol.

Polysomnography

An unattended home PSG was scheduled as soon as possible after recruitment. A 2-person, mixed-sex team arrived at the child's home approximately 1 hour prior to the child's normal bedtime. The methods for obtaining and processing PSG data have been described previously [21]. Briefly, PSGs were acquired using the Compumedics PS-2 system (Abbotsford, Victoria, Australia). The Compumedics software system was used to process all PSG data. Apneas were scored if the amplitude (peak to trough) of the airflow signal using the thermister decreased below at least 25% of the amplitude of baseline breathing (identified during a period of regular breathing with stable oxygen levels) and if this change lasted for more than 6 seconds or two breath cycles. Apneic events were classified as obstructive or central by the presence or absence of ventilatory effort respectively. Hypopneas were designated if the amplitude of any respiratory signal decreased below 70% of the base line amplitude and if the thermister signal did not meet the criterion for apnea. After full scoring, analysis software was used to link each event to data from the oxygen saturation and electroencephalogram channels. Respiratory events were marked independently of concomitant oxygen desaturation; this allowed characterization of events according to differing degrees of associated desaturations or various combinations of these measures. In this way, the Respiratory Disturbance Index was defined as the number of respiratory events (apneas and hypopneas) per hour of the total sleep time. Scoring software generated the RDI based on events independent of any oxygen desaturation (RDI0) and associated with a 2% (RDI2) or 3% (RDI3) oxygen desaturation.

Behavior Assessment

Approximately 4 weeks after their PSG, children were scheduled to undergo an extensive neurocognitive test battery as previously reported [22]. At that time, behavior assessments were obtained from the parents using the Revised Conners' Parent Rating Scale (CPRS-R) and the Child Behavior Check List (CBCL).

The CPRS-R is a popular research and clinical tool for obtaining parent reports of childhood behavior problems. It is a well-validated 80 item behavior rating scale that measures symptoms of attention deficit hyperactivity disorder (ADHD) (hyperactivity, impulsivity, and inattention) as well as comorbid behaviors such as oppositional behavior, anxiety, and somatic complaints [23, 24]. The 12 scales and the symptoms or problems that are assessed are shown in Table **1**.

Table 1. Conners Parent Rating Scale-Revised (CPRS-R) Scales, Symptoms and Mean T Scores

Scales	Symptoms/Problems Measured	Mean	SD	Min	Max
Oppositional	Angry, resentful, fights & argues, easily annoyed	51.9	10.5	39	90
Cognitive problems	Difficulty in concentrating/completing work	52.3	10.8	40	90
Hyperactivity	Excitable, impulsive, restless, hard to control	54.2	11.4	42	90
Anxious Shy	Timid, easily frightened, shy, withdrawn, clings to parents	52.1	11.0	40	90
Perfectionism	Sets very high goal for self, everything must be just so	49.6	8.9	40	90
Social Problems	No friends, does not know how to make friends	51.6	10.8	45	90
Psychosomatic	Aches, pains, headaches, stomach aches, seems tired	52.3	11.5	42	90
ADHD Index	Easily distracted, short attention span, easily frustrated	52.6	11.1	40	90
Global Index Total	Overactive, impulsive, easily distracted, cries often/easily	52.2	11.0	40	90
DSM Inattentive	Avoids/difficulty in engaging in tasks, forgetful, distracted	52.0	11.0	40	90
DSM Hyperactive Impulsive	Talks excessively, interrupts others, always 'on the go'	55.1	11.4	41	90
DSM Total	Combined DSMI and DSMH	53.7	11.3	40	90

Table Abbreviations: ADHD = Attention deficit hyperactivity disorder; DSM = Diagnostic and Statistical Manual; DSMI = DSM Inattentive; DSMH = DSM Hyperactive.

Behaviors are rated on a four-point scale that ranges from "Very Much True"(3), "Pretty Much True"(2), "Just A Little True"(1) and "Not True At All"(0). A T-Score is derived from the raw scores for each scale, based on a large age and gender specific normative sample. T-scores are standard scores that are calculated from raw scores such that each scale will have the same mean (= 50) and standard deviation (SD = 10). T-scores allow each obtained score to be compared to the same reference value. A T-score over 65 is considered to indicate moderate to severe clinical impairment.

The CBCL allows assessment of 118 parent-reported behavior and emotional problems of children aged 4-18 years [25]. Parents rate their children on a three-point scale (Not True, Somewhat True, or Very/Often True). In addition to eight syndrome scales such as Withdrawn, Somatic complaints, Anxious/Depressed, Social problems, Thought Problems, Attention problems, Delinquent behavior and Aggressive behavior, the CBCL includes a Total Problem Score, and higher order Internalizing and Externalizing scales. Internalizing scales include Anxious/Depressed, Withdrawn and Somatic Complaints. Externalizing scales include Aggressive Behavior and Delinquent Behavior. Some symptoms of each behavior are shown in Table **2**. Identical to CPRS-R scales, a T-Score for the CBCL is derived from the raw scores for each scale, based on a large age and gender specific normative sample. It has been suggested that a T-score over 65 indicates moderate to severe clinical impairment. Therefore, a T-score of 65 was used as the cutoff point in our analysis.

Statistical Methods

Logistic regression was used to determine the level of respiratory disturbance index that would predict a greater likelihood of having a T score > 65 for the various subscales of the CPRS-R and CBCL. The RDI and behavior measures were categorized using cut points found to be associated with sleep or behavioral problems on previous studies [1, 12, 22, 26, 27]. RDI0 (the number of respiratory events per hour independent of oxygen desaturation) was categorized by cut points at 3, 5 and 7 events per hour; RDI2 (the number of events per hour associated with a 2% or greater oxygen desaturation) was categorized by cut points at 0.5, 1 and 2 events per hour; while RDI3 (the number of events per hour associated with a 3% or greater oxygen desaturation) was categorized at 0.5 and 1. Thus, the dependent variables were the dichotomized CPRS-R and CBCL scales, while the independent variables were the three definitions of RDI, fitted at the above selected cut points. The following potential covariates were included in the regression models: WASI IQ (Wechsler Abbreviated Scale of Intelligence), age, gender, ethnicity and obesity. 95% confidence intervals that excluded 1 were considered statistically significant. Statistical analyses were performed using Stata 9 for Windows (Stata Corporation; College Station, TX).

RESULTS

There were 403 children with polysomnographic data, all of whom had CBCL behavioral data; 397 also had CPRS data. The sample consisted of 52% boys, 60.8% Caucasian, and 9.2% of children with BMI greater than the 95th percentile (defined as obese). The mean age of the sample was 8.3 years (SD = 1.6, Median = 8, Range 6-11) and the mean Wechsler Abbreviated Scale of Intelligence (WASI) full scale IQ was 106.1 (SD = 15.46).

The range and the means for the three definitions of RDI used in this study were as follows. RDI0 ranged from 0 to 72.3 with a mean of 5.24. The prevalence rates for RDI0 in the following categories were RDI0<3 28.54%, RDI0≥3 and <5: 29.79%, RDI0≥5 and <7: 22.29%, and RDI0≥7: 19.38%. RDI2 ranged from 0 to 48.5 with a mean of 1.90. The prevalence rates for RDI2 in the following categories were RDI2<0.5: 17.50%, RDI2 ≥0.5 and <1: 25.00%, RDI≥1 and ≤2: 28.13%, and RDI2>2: 29.38%. The mean of RDI3 dropped further to 0.9 with a range from 0 to 29.1. The prevalence rates for RDI3 in the following categories were RDI3<0.5: 50.63%, RDI3 ≥0.5 and <1: 25.42%, and RDI3≥1: 23.96%. There were no significant differences related to ethnicity or gender. Tables **1** and **2** provide the overall means and range of scores on the CPRS-R and the CBCL for the study sample.

Table 2. Child Behavior Check List Scales, Symptoms and Mean T Scores

Scales	Symptoms/Problems to Measure	Mean	SD	Min	Max
Withdrawn	Shy, timid, would rather be alone, refuse to talk, unhappy, depressed	53.8	6.3	35	85
Somatic complaints	Feel dizzy, nausea, pains, overtired	55.7	7.1	41	82
Anxious/Depressed	Lonely, cries a lot,	54.5	7.6	36	88
Social problems	Too dependent, not get along w. peers	54.1	7.5	50	91
Thought problems	Strange idea/behavior, see/hear things	54.6	6.9	50	82
Attention problems	Can't concentrate, acts too young, confused	55.1	8.3	50	88
Delinquent behavior	Lack guilt, bad companions, lies, steals alcohol/drug	54.4	6.8	50	82
Aggressive behavior	Argues, brags, mean to others, destroy things	53.8	6.8	50	82
Total score	Combination of all symptoms	49.8	12.4	37	82
Internalizing	Withdrawn, somatic, anxious	50.4	11.2	33	81
Externalizing	Aggressive, delinquent	48.5	11.0	30	78

In Table **3** are shown the associations between RDI0 and the various subscales of the CPRS-R and the CBCL. For this analysis, RDI0 was grouped into four categories: <3 (referent), between 3 and 5, between 5 and 7 and more than 7. This was done to create adequate numbers for analysis in each category, and also to explore whether any associations between RDI0 and the CPRS-R and CBCL represented progressive or threshold relationships.

It can be seen from Table **3** that for CPRS-R oppositional, psychosomatic, and CBCL somatic complaints, social problems, aggressive behavior and externalizing scales, there are significant odds ratios (OR) ranging from 2.73 to 5.26 for the RDI0 group ≥ 7 with highly significant p-values, indicating that those subjects in the RDI0 ≥ 7 group, are 2.73-5.26 times more likely to have such behavior problems than the group with RDI0 less than 3. In contrast for these behavior scales, the OR for RDI0 groups between 3 and 5 and between 5 and 7 are not significant. For all other CPRS-R and

Table 3. Associations Between CPRS-R and CBCL Scales and RDI0

CPRS-R Scales	3< = RDI0<5		5< = RDI0<7		RDI0> = 7	
	N = 124		N = 85		N = 77	
	OR	p	OR	p	OR	p
Oppositional	0.74	0.521	0.75	0.577	2.73	0.022*
Cognitive Problems	0.78	0.545	1.1	0.831	1.74	0.185
Hyperactive	0.9	0.77	0.81	0.59	0.76	0.504
Anxious-shy	1.49	0.329	1.96	0.122	1.01	0.99
Perfectionism	3.87	0.095	2.85	0.24	4.48	0.074
Social problems	1.3	0.604	1.79	0.274	2.54	0.064
Psychosomatic	4.6	0.004**	2.98	0.066	5.26	0.003**
ADHD Index	0.85	0.711	1.53	0.344	1.74	0.221
Global Total	0.6	0.213	0.62	0.289	1.22	0.634
DSM Inattentive	0.88	0.77	1.26	0.608	1.69	0.226
DSM Hyperactive	0.78	0.495	0.93	0.858	0.97	0.944
DSM Total	0.62	0.263	1.13	0.769	1.31	0.522
Reference Group is RDI <3 (N = 111). * p<0.05 ** p<0.01 *vs* Reference Group.						
CBCL Scale	**3< = RDI0<5**		**5< = RDI0<7**		**RDI0> = 7**	
	N = 124		**N = 86**		**N = 77**	
	OR	**p**	**OR**	**p**	**OR**	**p**
Withdrawn	1.88	0.26	0.9	0.883	1.67	0.396
Somatic Complaints	1.54	0.41	2.25	0.124	3.33	0.017*
Anxious/Depressed	1.36	0.543	2.32	0.095	1.92	0.204
Social Problems	2.18	0.146	2.12	0.205	4.16	0.009**
Thought Problems	0.87	0.736	0.61	0.321	1.65	0.248
Attention Problems	1.32	0.495	1.13	0.78	1.87	0.141
Delinquent Behavior	1.14	0.76	1.04	0.937	1.07	0.894
Aggressive Behavior	1.29	0.652	1.65	0.402	3.06	0.039*
Total Score	1.06	0.895	1.14	0.778	2.11	0.08
Internalizing	1.18	0.728	2.06	0.132	1.69	0.284
Externalizing	1.71	0.33	1.29	0.676	3.54	0.02*
Reference Group is RDI <3 (N = 116). * p<0.05 ** p<0.01 *vs* Reference Group.						

Table Abbreviations: ADHD = Attention deficit hyperactivity disorder; DSM = Diagnostic and Statistical Manual; DSMI = DSM Inattentive; DSMH = DSM Hyperactive.

CBCL subscales, there were no significant differences between higher RDI0 groups and the reference group.

A similar analysis was done on RDI2, which also was grouped into four categories as follows: less than 0.5 (referent), between 0.5 and 1, between 1 and 2, and more than 2. The regression result is shown in Table **4**. It can be seen that for CPRS-R social problems, psychosomatic, and CBCL somatic complaints and social problems, there are non-significant odds ratios for the RDI group between 0.5 and 1 and for the RDI group between 1 and 2. While for the RDI group of more than 2, there is an increase in odds ratios ranging from 3.63 to 8.23 with significant p-values.

Finally, RDI3 was divided into three groups as follows: RDI3 less than 0.5 (referent), and groups between 0.5 and 1, and more than 1. Only three groups were used because of the paucity of subjects with RDI3 exceeding 2. As shown in Table **5**, for RDI3 between 0.5 and 1 there are significant ORs for CPRS-R social problems and psychosomatic, and CBCL withdrawn, anxious/depressed, social problems, delinquent behavior, aggressive, total, internalizing and exter-

Table 4. Associations Between CPRS-R and CBCL Scales and RDI2

CPRS-R Scale	.5< = RDI2<1		1< = RDI2<2		RDI2> = 2	
	N = 105		N = 107		N = 116	
	OR	p	OR	p	OR	p
Oppositional	0.75	0.585	0.51	0.223	1.47	0.406
Cognitive Problems	0.86	0.757	1.18	0.724	1.45	0.408
Hyperactive	0.75	0.474	0.57	0.186	0.66	0.308
Anxious-shy	1.45	0.463	1.81	0.239	1.89	0.193
Perfectionism	2.73	0.375	4.31	0.184	5.56	0.11
Social problems	1.88	0.376	2.68	0.152	4.24	0.028*
Psychosomatic	6.76	0.014*	4.36	0.065	8.23	0.006**
ADHD Index	0.82	0.693	1.07	0.897	1.63	0.302
Global Total	0.6	0.27	0.68	0.415	0.89	0.795
DSM Inattentive	0.91	0.852	1.17	0.756	1.6	0.313
DSM Hyperactive	0.67	0.314	0.6	0.213	0.72	0.39
DSM Total	0.6	0.257	0.51	0.159	1.01	0.983
Reference Group is RDI <0.5 (N = 69). * p<0.05 ** p<0.01 *vs* Reference Group.						
CBCL Scale	**.5< = RDI2<1**		**1< = RDI2<2**		**RDI2> = 2**	
	N = 104		**N = 112**		**N = 112**	
	OR	**p**	**OR**	**p**	**OR**	**p**
Withdrawn	3	0.262	6.16	0.05	5.12	0.077
Somatic Complaints	2.89	0.133	3.1	0.108	4.67	0.022*
Anxious/Depressed	0.77	0.68	1.97	0.214	1.64	0.36
Social Problems	1.36	0.668	3.68	0.044*	3.63	0.045*
Thought Problems	1.04	0.936	0.58	0.297	1.5	0.372
Attention Problems	0.91	0.844	1.35	0.506	1.22	0.661
Delinquent Behavior	1.48	0.462	1.72	0.301	1.2	0.732
Aggressive Behavior	0.62	0.459	1.27	0.67	1.35	0.586
Total Score	0.74	0.554	1.25	0.631	1.29	0.576
Internalizing	1.48	0.501	2.1	0.184	1.89	0.251
Externalizing	1.49	0.533	1.91	0.301	1.88	0.302
Reference Group is RDI <0.5 (N = 75). * p<0.05 ** p<0.01 *vs* Reference Group.						

Table Abbreviations: ADHD = Attention deficit hyperactivity disorder; DSM = Diagnostic and Statistical Manual; DSMI = DSM Inattentive; DSMH = DSM Hyperactive.

nalizing. In addition, for RDI3>1, the ORs are still significant for CPRS-R social problems and psychosomatic although attenuated. In addition, the CBCL scales are no longer significant.

Table 5. Associations Between CPRS-R and CBCL Scales and RDI3

CPRS-R Scale	.5 = <RDI3<1		RDI3> = 1	
	N = 102		N = 93	
	OR	p	OR	p
Oppositional	2.07	0.057	1.23	0.622
Cognitive Problems	1.43	0.517	1.23	0.578
Hyperactive	1.07	0.85	0.77	0.471
Anxious-shy	1.99	0.057	1.35	0.429
Perfectionism	1.9	0.27	2.14	0.175
Social problems	3.25	0.006**	2.56	0.032*
Psychosomatic	2.47	0.02*	2.45	0.021*
ADHD Index	1.61	0.207	1.31	0.493
Global Total	1.77	0.113	1.05	0.893
DSM Inattentive	1.53	0.25	1.34	0.442
DSM Hyperactive	1.51	0.195	0.93	0.824
DSM Total	1.72	0.133	1.27	0.534
Reference Group is RDI <0.5 (N = 202). * p<0.05 ** p<0.01 *vs* Reference Group.				
CBCL Scale	**.5 = <RDI3<1**		**RDI3> = 1**	
	N = 101		**N = 92**	
	OR	**p**	**OR**	**p**
Withdrawn	4.17	0.006**	2.17	0.163
Somatic Complaints	1.6	0.27	2.12	0.058
Anxious/Depressed	2.64	0.02*	1.91	0.132
Social Problems	4.17	0.001**	1.97	0.151
Thought Problems	1.09	0.826	1.25	0.558
Attention Problems	1.5	0.244	1.04	0.92
Delinquent Behavior	2.4	0.018*	0.71	0.469
Aggressive Behavior	2.67	0.019*	0.96	0.944
Total Score	2.23	0.026*	1.38	0.398
Internalizing	2.23	0.044*	1.4	0.416
Externalizing	2.69	0.02*	1.07	0.894
Reference Group is RDI <0.5 (N = 210). * p<0.05 ** p<0.01 *vs* Reference Group.				

The preceding analyses using 3 different definitions of RDI suggest that the likelihood of having a clinically significant CPRS-R or CBCL subscale score was not necessarily progressive or linear across RDI categories, and the following cutpoints were indicators of clinically significant SDB: RDI0 ≥ 7, RDI2 ≥2 and RDI3 ≥0.5 events per hour of sleep. To further define these relationships, RDI0, RDI2 and RDI3 were grouped into two categories with a single cutoff point, one group below the cutoff point and the other equal or more than the cutoff point. The odds ratios between these two groups were computed, adjusting for the same covariates as used before, IQ, age, gender, ethnicity and obesity (Table **6**). In general, most of the associations remained the same although there was attenuation of the ORs for some of the subscales.

DISCUSSION

In this study, we have analyzed the association between SDB in school-aged children and their parents' assessment of behavior in order to identify the minimum severity of SDB associated with a moderate to severe degree of clinical behavioral impairment. Using three definitions of RDI, we found that there were thresholds of SDB severity corresponding with an increased likelihood of elevated CPRS-R and CBCL subscale scores. Furthermore, the RDI threshold level decreased as the requirement for oxygen desaturation to define a respiratory event increased.

We found that irrespective of the definition of RDI used, several CPRS-R and CBCL subscales were associated with SDB. These results are consistent with the report by Rosen *et al.* who observed that children with SDB in the Cleveland Children's Sleep and Health Study also had elevated scores in a number of domains assessed by the CPRS-R and CBCL [13]. Although the latter study was performed in a general population cohort similar to ours, SDB was identified using either a limited channel cardiorespiratory monitor or parent reported "loud snoring". Most (reviewed in [3, 4]), but not all [15, 16] clinical studies also have found either evidence of abnormal behavior in children with SDB compared to normal subjects, or an increased percentage of children with SDB showing behavior problems in a clinically relevant range. This analysis provides additional evidence in a general population that SDB is associated with an increased likelihood of abnormal behavior in preadolescent children.

The mechanism by which SDB results in abnormal behavior in children has not been conclusively established. Two factors are proposed to be important. Intermittent hypoxia related to SDB is a possible mechanism and has been shown in animal models to result in both structural and behavioral deficits [28, 29]. However, SDB frequently occurs in children without severe hypoxia. Sleep disruption and fragmentation related to SDB is the other major mechanism that may be operative. Both non-SDB sleep fragmentation and sleep restriction can produce neurobehavioral abnormalities in children [30, 31]. Nevertheless, arousals related to SDB are not always observed in children [32]. It is plausible that both intermittent hypoxia, and sleep disruption and restriction are important, but whether there are other mechanisms involved remains to be determined.

Although the RDI is the generally accepted metric used to indicate the severity of SDB in both adults and children, there is little consensus as to the best definition particularly in children. A number of RDI thresholds have been used ranging from 1 to 5 events per hour with varying requirements for associated oxygen desaturation [13, 22, 26, 33,

Table 6. Dichotomous Associations Between RDI Definitions and CPRS-R and CBCL

CPRS Scale	RDI0> = 7		RDI2> = 2		RDI3> = 0.5	
	N = 77		N = 116		N = 195	
	OR	p	OR	p	OR	p
Oppositional	3.27	0.001**	2.07	0.029*	1.62	0.146
Cognitive Problems	1.85	0.079	1.44	0.249	1.33	0.349
Hyperactive	0.83	0.612	0.9	0.728	0.92	0.751
Anxious-shy	0.72	0.417	1.3	0.414	1.65	0.103
Perfectionism	1.79	0.267	1.95	0.159	2.02	0.15
Social problems	1.96	0.086	2.19	0.027*	2.89	0.005**
Psychosomatic	1.93	0.07	1.93	0.043*	2.46	0.007**
ADHD Index	1.63	0.195	1.71	0.105	1.46	0.237
Global Total	1.63	0.172	1.24	0.512	1.39	0.29
DSM Inattentive	1.66	0.162	1.56	0.166	1.43	0.246
DSM Hyperactive	1.08	0.822	0.99	0.992	1.2	0.494
DSM Total	1.48	0.277	1.54	0.174	1.48	0.196
Reference Groups: RDI <7 (N = 320), RDI<2 (N = 281), and RDI<0.5 (N = 202) respectively. * p<0.05 ** p<0.01 *vs* Reference Group.						
CBCL Scale	**RDI0> = 7**		**RDI2> = 2**		**RDI3> = 0.5**	
	N = 77		**N = 112**		**N = 193**	
	OR	**p**	**OR**	**p**	**OR**	**p**
Withdrawn	1.3	0.588	1.45	0.397	3.04	0.016*
Somatic Complaints	2.22	0.032*	1.91	0.059	1.86	0.072
Anxious/Depressed	1.33	0.48	1.31	0.456	2.25	0.025*
Social Problems	2.45	0.024*	1.76	0.124	2.99	0.004**
Thought Problems	1.96	0.073	1.77	0.084	1.17	0.623
Attention Problems	1.63	0.161	1.11	0.736	1.26	0.433
Delinquent Behavior	1.01	0.989	0.83	0.625	1.46	0.254
Aggressive Behavior	2.41	0.033*	1.41	0.378	1.75	0.143
Total Score	1.99	0.049	1.3	0.417	1.78	0.064
Internalizing	1.28	0.528	1.2	0.608	1.78	0.091
Externalizing	2.68	0.016*	1.25	0.575	1.8	0.122
Reference Groups: RDI <7 (N = 326), RDI<2 (N = 291), and RDI<0.5 (N = 210) respectively. * p<0.05 ** p<0.01 *vs* Reference Group.						

Table Abbreviations: ADHD = Attention deficit hyperactivity disorder; DSM = Diagnostic and Statistical Manual; DSMI = DSM Inattentive; DSMH = DSM Hyperactive.

34]. As demonstrated in a recent study by Tang *et al.* [35], variation in the definition used to define a respiratory event can lead to a 20 fold difference in the median RDI within a population. The lack of an accepted standard for RDI has important implications. From a clinical perspective, it becomes another factor hindering identification of SDB in children. From an epidemiological and public health viewpoint, estimates of SDB prevalence become imprecise. Furthermore, comparison of research studies using different definitions is difficult. Unfortunately, there have been relatively few studies in adults or children that have attempted to establish the boundary between normal and SDB. The first such study in children was performed by Marcus *et al.* in 50 normal children. They found apneic events to be rare and suggested that an apnea index ≥ 1 was abnormal [33]. However, hypopneas were not scored and the study population included some older adolescents approaching adulthood. Subsequently, several studies reported that apneas and hy-

popneas were uncommon in younger children, but event definitions were not always comparable among all studies [34, 36-39]. Additionally, the frequency of events as determined in asymptomatic children was used to define the normal range for RDI. In contrast, in an earlier study from the TuCASA cohort, using several definitions of RDI, we identified threshold values for each definition that were associated with a greater likelihood of SDB symptoms [26]. Our findings in this current analysis extend our previous observations to include behavioral outcomes. Nevertheless, there are some small differences between the studies. Both analyses indicated that for RDI2, a cutpoint of 2 was optimum. However, the RDI0 analysis using SDB symptoms suggested a cutpoint of 5, whereas behavioral data indicate a cutpoint of 7. Similarly, RDI3 symptom analysis indicated a cutpoint of 1 in comparison to 0.5 using behavioral data. These findings suggest that the severity of SDB required to produce clinical symptoms may be different than the severity resulting in behavioral abnormalities.

We observed that as the definition of a respiratory event required increasing oxygen desaturation, the number of events identified decreased. These findings are similar to those observed by Tang *et al.* in children [35] and Redline *et al.* [40] in adults. They further reinforce the concept that event definition especially with respect to assessment oxygen desaturation is critically important in identifying the presence of SDB in children.

Several caveats should be considered in the interpretation of this study. Firstly, this study is correlational and does not provide confirmation of a causal relationship between RDI and behavior problems. Thus, although reverse causality such that behavior problems lead to an increase in RDI cannot be excluded, biologic plausibility is unlikely. Secondly, behavior measures were dependent upon parent report only. The study did not engage teachers or young subjects in evaluating behavior. Multiple informants and multiple ways of measuring behavior provide the best and most evidence of behavior problems. It is possible that different findings may have been observed if multiple or alternative assessments of behavior had been utilized. Thirdly, there were insufficient subjects for certain combinations between RDI3 and behavior groups. Thus we were not able to detect a significant odds ratio for RDI3 >1 compared with the corresponding reference group. A larger number of subjects also would have increased the precision in our odds ratio estimates. Fourth, no associations between SDB and behaviors such as hyperactive, perfectionism and ADHD were detected. Behaviors may have different specificity and sensitivity in relation to SDB. Further studies to explore these relationships are required. Fifth, scoring of SDB events in this study was performed using data from thermisters. Although we have demonstrated that nasal pressure monitoring in children will identify a greater number of respiratory events [41], use is associated with a greater rate of malfunction, and it is not recommended as the primary flow monitor in children [42]. Nevertheless, if nasal pressure monitoring is used to identify more subtle SDB events, the thresholds proposed in this study may not be applicable. Given the growing use of nasal pressure monitoring, additional studies examining the relationship between SDB and behavior in children are needed. Sixth, although central apneas were included in our definition of RDI, they represented a very small proportion of the total number of respiratory events, and thus we do not think their presence altered our conclusions. Finally, while we propose cutpoints for 3 different definitions of RDI, it remains unclear whether any of these RDI definitions are superior to the others. This continues to be an area that requires additional investigation.

Despite the aforementioned limitations, to the best of our knowledge, this study is the first to use behavioral outcome data to define RDI thresholds for the identification of SDB in children. Additional strengths are the large size of the cohort, use of a community sample in lieu of a clinic derived cohort and home PSG to reduce disruption in sleep from a laboratory environment. Furthermore, use of the definitions proposed in this study should aid clinicians in identifying which children have SDB and thus may require treatment. They also will facilitate comparison of PSG results obtained at different times from the same child. Finally, from a public health perspective, they will assist investigators in determining the true prevalence of childhood SDB in various populations.

In conclusion, this analysis found an increased risk of behavior problems such as somatic complaints, oppositional or aggressive behaviors and social problems, associated with sleep-disordered breathing in school-aged children. RDI cut points for three definitions of SDB are proposed. These cut points should help physicians identify children with SDB that may have an increased risk of abnormal behavior, and it may help determine appropriate treatments. Furthermore, these analyses provide additional evidence that evaluation of SDB should be considered in children exhibiting moderate to severe levels of behavior problems.

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