Brain & Development 41 (2019) 662–670

BRAIN & DEVELOPMENT
Official Journal of the Japanese Society of Child Neurology

www.elsevier.com/locate/braindev

Original article

Event-related potentials and behavior performance scores in children with sleep-disordered breathing

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Received 4 July 2018; received in revised form 8 April 2019; accepted 11 April 2019

Abstract

Objective: To explore impaired cognition characteristics and abnormal behavior in children with Sleep-Disordered Breathing (SDB) via Event-Related Potentials (ERPs), continuous performance testing (CPT), and the Child Behavior Checklist (CBCL).

Methods: A total of 108 children aged 6–8 years old were recruited, including fifty-four children (28 boys) with SDB and fifty-four normal children (28 boys). CBCL and Chinese version of the OSA-18 questionnaire were administered. Nineteen children with SDB (OSA-18 questionnaire value >60) and Nineteen normal children completed a CPT task. ERP was extracted using the BESA software.

Results: No significant differences in the correct number, reaction time, or the number of commission error were noted between the CPT of the two groups ($P > 0.05$). The ERP Go-P3 amplitudes at F3, Fz and F4 of the SDB group were significantly higher than those of the control group ($P < 0.05$). The NoGo-N2 amplitudes at F3 and Fz of the SDB group were significantly lower than those of the control group ($P < 0.05$). The Fz and F4 Go-P3 and FZ NoGo-P3 latency of the SDB group were significantly longer than those of the control group ($P < 0.05$). However, among boys, the CBCL scores of the SDB group including the subscores, schizo, somatic complaints, compulsion, aggression, and hyperactivity, as well as the total score, were significantly higher than the control group (all $P < 0.05$).

Conclusion: Children with SDB demonstrate significant functional deficits in regard to conflict monitoring, attention, and inhibition. The frontal region is the primary area of dysfunction, especially in the left brain region, and inhibition function dysfunction may be a common pathogenesis of SDB and ADHD. Moreover, boys with SDB may exhibit more behavior problems when compared to girls.

Keywords: Sleep-disordered breathing; Event-related potentials; Behavior; Children

1. Introduction

Sleep-disordered Breathing (SDB) is a common pediatric disorder. According to its physiological characteristics, it may be divided into primary snoring (PS), upper airway resistance syndrome, and obstructive sleep apnea syndrome (OSAS). Although it was previously thought

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https://doi.org/10.1016/j.braindev.2019.04.008
0387-7604/

that only severe SDB could lead to impairment of cognitive function, mild SDB (like PS) significantly affects cognitive functions such as attention, mathematics, executive ability, and language skills in children [1]. O'Brien et al. [2] found that the neural cognitive function of children with primary snoring was lower than in those who did not snore, and that the former were more likely to have symptoms including inattention, anxiety, and depression. Similarly, children with sleep apnea are more likely to be irritable, less alert, and emotionally unstable and depressed [3]. Compared with non-snoring children, PS children are more prone to hyperactivity (39% vs 20%), lack of focus (33% vs 11%), and subpar performance in mathematics (29% vs 16%), science (23% vs 12%), and spelling (33% vs 20%) [4].

The language function score of children with frequent snoring is lower (as gauged by understanding of instructions). Snoring children when compared with their non-snoring counterparts, regardless of OSA, more likely to develop cognitive and behavioral disorders [5]. In these children, polysomnography (PSG) parameters of other sleep-related breathing disorders, including partial airway obstruction, were not present. Thus, the PSG parameters of snoring children were not related to the results of the neuropsychological tests [5]. SDB's impairment of language ability may further affect learning performance, social and emotional behavior [6]. While the effect of SDB on children's cognition has received much attention, there is still a lack of sufficient research on the characteristics of cognitive impairment caused by SDB.

Attention is a necessary condition for optimal learning. It comprises a series of cognitive processes, such as optimization of detection, identification of stimuli and stimulation of operation. Attention can be divided into continuous, selective, and separated attention, thus representing a group of variables that contribute to learning and memory. Different categories of attention, such as selective and sustained attention, can be evaluated by objective assessment methods, such as auditory or visual continuous performance tests (CPT), which can provide more accurate assessments than parents' and teachers' reports. In a small study of 13 snoring children, Kennedy et al [7] using an auditory CPT found selective- and sustained-attention impairments in children with habitual snoring. Galland et al [8] using a visual CPT test reported that children with SDB were more distracted and impulsive than those without SDB. SDB children's hearing and visual attention were impaired, compared to normal children's [9]. Daytime symptoms of OSA can manifest as paradoxical hyperactivity, neurocognitive deficits, and behavioral problems such as aggressivity, impulsivity, and oppositional behavior [10].

In order to explore the characteristics of cognitive impairment and the behavioral changes of school-age children with SDB, we applied a highly sensitive approach to Event-Related Potentials (ERPs), utilizing both a continuous performance task and the Child Behavior Checklist (CBCL) scale. The recording of ERPs is a highly sensitive technique that is both safe and well tolerated in children.

We hypothesized that frequent snoring may disrupt neuropsychological functioning in snoring children by impairing the prefrontal areas, which are associated with attention. This study's purpose was to compare indicators of impaired cognition and abnormal behavior between children who snored frequently by parental report and a matched control group who had no reported history of snoring utilizing the CPT-AX, ERP and CBCL.

2. Participants and methods

2.1. Participants

SDB group: Children aged 6–8 years with sleep problems were recruited from the respiratory, pediatric, psychiatric, and otolaryngologic clinics between November 2014 and August 2016. The inclusion criteria included: sleep snoring >3 nights/week, duration >6 months, and night sleep with apnea (more than 5 s) [1]. All but one parent reported recognition of snoring and its severity, often commenting on the level of noise their children made ("If you laid next to her she sounded like a grizzly bear.") [11]. No special treatment was administered before the test. The exclusion criteria were as follows: (1) Specific diseases known to cause obstructive sleep apnea syndrome (OSAS) in children: craniofacial malformation; hypoplasia of the face (such as, Down syndrome, Crouzon syndrome, cartilage hypoplasia); mandibular hypoplasia, such as Skin-Luo syndrome, mandibular facial development abnormalities; and others, such as mucopolysaccharide storage disease and metabolic diseases (such as osteosclerosis) causing craniofacial structural abnormalities; (2) Nerve regulation: systemic muscular hypotonia (neuromuscular disease; the application of sedative drugs; preterm birth; or severe asphyxia at birth; (3) Prior history of cerebral palsy, epilepsy or other neurological conditions; (4) Acute infection within 1 week prior; (5) Other severe heart, lung, liver and kidney diseases.

Control group: Fifty-four healthy children were randomly selected to match the SDB children with age and sex from a common primary school in this city.

The two groups of children were all right-handed. Their corrected or uncorrected visual acuity was greater than 1.0. There was no significant difference in age and sex between the two groups ($P > 0.05$).

All subjects completed the OSA-18 questionnaire and CBCL on the first visit after providing written informed consent. The good internal consistency and validity of OSA-18 with overnight polysomnography was confirmed [12]. The weight and height of each child were

measured. Nineteen children with SDB (OSA-18 questionnaire value >60) and nineteen normal children completed a CPT. There was no significant demographic and BMI difference between patients and controls (Table 1).

The study protocol and the informed consent form were approved by Ethics Committee of the Children's Hospital of Changzhou. Written informed consent and verbal assent were obtained from parents and children. No monetary incentive was provided.

2.2. Methods

2.2.1. ERP methods

CPT task: A continuous performance task (CPT-AX task) was utilized that composed of 10 different numerals from 0 to 9. The numeral 1 is a prompt message, and the emergence of numeral 9 after 1 is taken as the target or Go condition. Other figures besides 9 emerging after 1are counted as not targets (the NoGo condition). Emergence of other figures (0, 2, 3, 4, 5, 6, 7 and 8) after 1 is referred to as the distraction condition. There are 500 conditions in total: 1–9 digit sequence 20%, 1-not-followed-by-9 digit sequence 20%, and other two-digit sequences appearing randomly. Subjects were instructed to press the right button only when noticing Fig. 2 appearing after 1, with a stimulus of 200 ms and a fixed stimulus-interval of 1300 ms. The stimulus emerged in the center of a cathode-ray-tube video display, with black screen and white picture, which was controlled by American E-prime software. Behavioral results were recorded automatically. The correct number, reaction time and the number of commission error were analyzed. The sum of the correct number and the omission number is 40 which is the total number of 9 appearing after 1.

Electroencephalograph testing: Electroencephalograph (EEG) data were recorded by a 46-channel Canadian digital electroencephalograph, in which recording electrodes were placed according to the standard international 10–20 system of electroencephalogram placement. Reference electrodes A1 and A2 were placed on the auricular lobe. Eye-movement recording electrodes were placed 2 cm above the outside of the left and right eyes. The scalp electrical resistance was less than 5,000 O. Bandpass amplifiers were 0.1–35.0 Hz, with a sampling rate of 500 Hz. Participants sat 80 cm away from the center of the computer screen, with 1.43° vertical angle and 0.72° horizontal angle of view, in a dimly lit soundproof room. Stimulus and behavior checking were conducted by US E-prime software. Stimuli appeared on the black computer screen in white letters. EEG testing began with a 3–5-minute baseline recording. Participants started testing after an instructive speech was broadcast and after they had an opportunity to become familiar with the test.

Analysis of brain: Using Germany BESA analysis software, ERP was extracted from the EEG through averaged superposition technology, baseline-adjusted 100 ms before visual stimulation started. The interval analyzed was from 200 ms before visual stimulation to 1500 ms after eliminating artifacts, such as blink, from EEG recordings (exclusion criteria: amplitude greater than ± 100 μv). The positive wave is called "P" while the negative wave is called "N". Therefore, the third positive wave is called "P3", and the second negative wave is called "N2".

Data measurement: We measured the amplitude and latency of N2 and P3 in the F3, FZ, and F4 leads (Go/NoGo Condition). Latency period was the duration from stimulation to each wave peak. The vertical distance from baseline to wave peak defined the amplitude. Measurements were done for all Go/NoGo conditions including both correct and incorrect results.

2.2.2. The Chinese version OSA-18 quality of life questionnaire

The OSA-18 contains 18 items divided into five subscales: sleep disturbance, physical symptoms, emotional distress, daytime function, and caregiver concerns. Each item is scored on a seven-point ordinal scale. The OSA-18 is graded to produce each item score, additional scores for five subscales, and total score. The OSA-18 total score is the sum of the 18 items, and therefore ranges from 18 (no impact on quality of life) to 126 (major negative impact). A value >60 was considered abnormal [13].

2.2.3. CBCL scale

The Child Behavior Checklist (CBCL) was from the Achenbach System of Empirically Based Assessment

Table 1
Comparison results of general information between SDB and control groups (x ± s, n = 19).

Group	Cases	Sex (Male)	Maternal Education	BMI	Age	Family Socioeconomic Status
SDB	19	9	2(0,2.0)	16.92 ± 2.58	6.92 ± 0.58	1.0(1,1)
Normal	19	10	2(1,2)	16.95 ± 2.47	7.09 ± 0.38	1(1,1)
t/z			0.935	−0.033	−1.103	−0.275
P			0.350	0.974	0.277	0.783

Note: BMI = body mass index. The levels of education were ranked as follows: below high school = 0; high school = 1; junior college or technical secondary school = 2; undergraduate or above = 3. The classification of family socioeconomic status was rated as: poor = 0, general = 1, good = 2, very good = 3.

(ASEBA) [14]. The questionnaires were completed by the parents. The CBCL contains 3 summary subscales-Internalizing, Externalizing, and Total Problem Behavior-which encompass scales of depression, withdrawn, somatic complaints, schizo/compulsion, hyperactivity, undiscipline, aggression, sexual Issues, poor interpersonal, cruel.

2.2.4. Statistical analysis

The date were analyzed with the statistical software package SPSS (Version 17.0). Some data, which were not normally distributed, were converted into normally-distributed data. Data in conformance with normal distribution were analyzed (showed in means ± standard deviation) through an independent sample T test. The data, which were not normally distributed, were analyzed shown in M [Q1 ~ Q3] through a Mann-Whitney U test. Significance criteria were set at P value lower than 0.05.

3. Results

3.1. Demographics

For 54 control and 54 SDB (28 boys in each group) children, the CBCL questionnaires were completed by their parents. CPT-AX was performed by 19 children with SDB (9 boys) and 19 control children (10 boys). The demographic profiles are displayed in Table 1. There was no significant difference in maternal education, body mass index, or family socioeconomic status between the two groups. The levels of education were ranked as follows: below high school = 0; high school = 1; junior college or technical secondary school = 2; undergraduate or above = 3. The classification of family socioeconomic status was rated as: poor = 0, general = 1, good = 2, very good = 3.

3.2. Neurocognition

3.2.1 On comparison of ERP behavior between the SDB group and the control group, there was no significant difference in the correct number, reaction time, or the number of commission error between the two groups ($P > 0.05$). The results were displayed in Table 2. The sum of the correct number and the omission number is 40 which is the total number of 9 appearing after 1.

3.2.2 Comparison of the Go/NoGo amplitude (μv) and latency (ms) in F3, FZ, and F4 of the SDB and the control group. Compared between the two groups, the Go-P3 amplitude of the SDB group was greater in F3, FZ and F4 and this difference was statistically significant ($P < 0.05$). Additionally, the NoGo-N2 amplitude of the SDB group was lower in F3, FZ ($P < 0.05$). The Fz and F4 Go-P3 and FZ NoGo-P3 latency of the SDB group were significantly longer than those of the control group ($P < 0.05$). These were shown in Tables 3–5. Therefore, the Go-stimulus results showed that the Go-P3 amplitude of the F3, FZ and F4 of the SDB group was higher than that of the control. The Fz and F4 Go-P3 latency of the SDB group were significantly longer than those of the control group ($P < 0.05$) (Fig. 1). NoGo-N2 amplitude of the F3 and FZ of the SDB group was lower than that of the controls. The FZ NoGo-P3 latency of the SDB group was significantly longer than that of the control group (Fig. 2).

3.3. CBCL results

Comparison of girls, there was no significant difference between the SDB and normal groups in CBCL (Table 6).The difference was statistically significant in male students in total score, schizo, somatic complaints, compulsion, hyperactivity and aggression between the SDB and normal group ($P < 0.05$, Table 7).

4. Discussion

The characteristics and mechanisms of SDB-induced cognitive impairment remain unclear. Bourke et al [15] found that SDB correlated with a higher rate of impairment of cognitive and learning ability for children, regardless of the severity of the disease.

Continuous operation testing (such as CPT-AX) is primarily used to detect deficits of attention and conflict monitoring functions, requiring the tester to press the key under the Go condition and to suppress the prepared response under the condition of NoGo. Different ERP components represent different cognitive functions. The P3 component is usually related to update of reactive working memory and attention resource allocation. P3 amplitude is related to the number of nerve cells involved in the brain work, the degree of excitation and the degree of mental energy input. The P3 amplitude of CPT-AX is closely related to the degree of attention investment [16]. The latency primarily reflects the speed of the brain's analysis, coding, and recognition of the stimulus [17], and is negatively related to attention and attention to stimulation [18]. The Go-P3 latency at Fz and F4 of the SDB group were significantly longer than in that of the control group ($P < 0.05$). It shows that children with SDB have delayed response, reduced speed, and impaired executive function.

The amplitude changes of P3 in SDB patients were not consistent with those in previous studies. Gosselin et al [19] found that the amplitude of P3 decreased in adult patients with OSAS. Thabit et al [16] found that auditory ERPs studied in SDB children aged 6–16 showed no change in the amplitude of P3. In this study, the amplitude of Go-P3 in frontal region of SDB children was higher than that of the control group, and this difference was significant. Jonkman et al [20] found that

Table 2
Results of behavioral comparison between SDB and control groups (x ± s, n = 19).

Group	Correct Number	Reaction Time (ms)	Commission Error
SDB	35.90 ± 4.73	526.67 ± 69.35	1(0,4)
Normal	35.63 ± 2.39	496.19 ± 80.79	2(0,3)
t/z	0.217	1.248	−1.372
P	0.829	0.220	0.191

Note: The numbers of the commission error are not normal distribution, so the average number, the 25% number and the 75% number are showed in the table.

Table 3
Comparison of F3-N2 and P3 between SDB and control groups (x ± s, n = 19).

Group	**Go**				**NoGo**			
	N2		P3		N2		P3	
	Amplitude	Latency	Amplitude	Latency	Amplitude	Latency	Amplitude	Latency
SDB	−6.80 ± 4.77	313.16 ± 23.44	10.57 ± 5.94	436.00 ± 60.45	−10.46 ± 4.45	322.84 ± 27.17	13.90 ± 7.62	457.16 ± 42.82
Normal	−7.07 ± 3.14	312.32 ± 21.79	6.44 ± 5.12	405.05 ± 31.69	−13.94 ± 3.36	321.16 ± 31.67	11.32 ± 7.62	444.74 ± 39.18
t	0.201	0.115	2.291	1976	2.720	0.176	1.040	0.933
P	0.841	0.909	0.028*	0.056	0.010*	0.861	0.305	0.357

Note: *p < 0.05.

Table 4
Comparison of FZ-N2 and P3 between SDB group and control group (x ± s, n = 15).

Group	Go				NoGo			
	N2		P3		N2		P3	
	Amplitude	Latency	Amplitude	Latency	Amplitude	Latency	Amplitude	Latency
SDB	−8.25 ± 5.59	313.79 ± 18.53	10.94 ± 5.84	440.63 ± 60.77	−12.51 ± 4.87	327.26 ± 21.03	15.63 ± 7.97	476.11 ± 41.49
Normal	−9.21 ± 3.46	314.11 ± 17.91	6.24 ± 4.55	407.05 ± 36.98	−15.46 ± 3.92	317.16 ± 31.95	14.23 ± 6.92	448.00 ± 34.37
t	0.635	−0.053	2.770	2.057	2.059	1.152	0.578	2.274
P	0.529	0.958	0.009*	0.047*	0.047*	0.257	0.567	0.029*

Note: *p < 0.05.

Table 5
Comparison of F4-N2 and P3 of SDB and control groups (x ± s, n = 15).

Group	Go				NoGo			
	N2		P3		N2		P3	
	Amplitude	Latency	Amplitude	Latency	Amplitude	Latency	Amplitude	Latency
SDB	−8.37 ± 5.15	319.68 ± 18.26	10.16 ± 5.88	442.95 ± 52.36	−11.61 ± 4.50	324.53 ± 16.94	13.28 ± 7.46	471.79 ± 37.17
Normal	−6.09 ± 3.45	312.42 ± 23.00	6.50 ± 4.68	409.26 ± 37.03	−12.67 ± 4.11	318.42 ± 24.65	10.25 ± 6.76	456.63 ± 36.79
t	−1.599	1.078	2.120	2.290	0.757	0.890	1.310	1.263
P	0.119	0.288	0.041*	0.028*	0.454	0.379	0.198	0.215

Note: *p < 0.05.

children's attention function commenced developing at the age of six and progressed rapidly between the ages of 7 and 10 years. Hypoxia and hypercapnia have an adverse effect, resulting in delayed reaction, reduced speed, and noticeable impairment of executive function. Due to intermittent sleep structure disorder and hypoxemia, the frontal-lobe development of SDB patients is often affected, causing impairment of cognitive function [21].

Some studies have found that patients with OSAS have extra brain involvement in the task of memory attention, suggesting that the activation of the brain is increased rather than decreased, which is believed to reflect a compensatory mechanism [22,23]. When children with OSAS finished a task of "oddball" stimulus attention, it was also found that the area beyond the frontal area was needed to complete it [24]. The increased amplitude of P3 in SDB children showed that

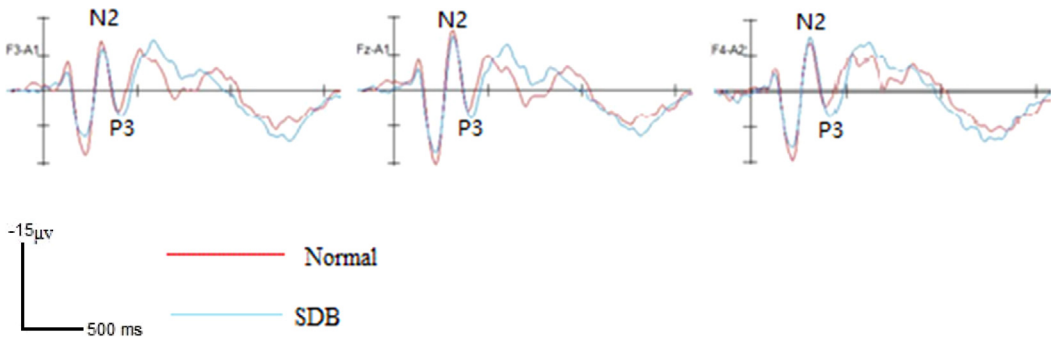

Fig. 1. Total average of Go: The Go-P3 amplitude at F3, FZ and F4 of SDB group was higher than that of normal children. The Fz and F4 Go-P3 latency of the SDB group were significantly longer than those of the control group.

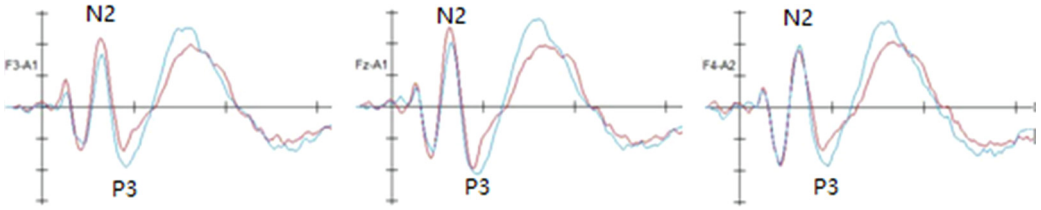

Fig. 2. Total average of NoGo: The Nogo-N2 amplitude at F3 of the SDB group was lower than that of the normal children. The FZ NoGo-P3 latency of the SDB group was significantly longer than those of the control group.

more resources were put into the task. Therefore, the SDB children, compared to their normal counterparts, activated more brain areas and utilized more attention resources to complete the same task. Because of this compensatory mechanism, there was no significant difference in behavioral results between the two groups. We found that there was a difference in Go-P3 latency between the SDB and control groups, which was consistent with the results reported by previous studies [18].

In the Go/NoGo paradigm, after successfully inhibiting the NoGo stimulus, N2 was clearly recorded in the prefrontal cortex, indicating that the NoGo-N2 was produced by impulse inhibition and the response to the conflict-monitoring function [25]. Conflict monitoring is mainly mediated by frontal-lobe processing [26]. The NoGo-P3 latency at Fz of the SDB group were significantly longer than that of the control group, which means that children with SDB have impaired function in dealing with suppression tasks. This study found that the NoGo-N2 amplitude in the left brain of SDB group was lower than that in the control group ($P < 0.05$). It is suggested that SDB children may be unable to inhibit unwanted information effectively, and secondary information therefore consumes more attention resources, leading to significant conflict-monitoring functional defects, and execution-function deficits in SDB children. Frontal-lobe function is particularly vulnerable because of metabolic and functional network barriers associated with sleep disruption and intermittent hypoxia [24], which lead to reduced attention monitoring, showing dysfunctional inhibition of processing.

While it is generally believed that attention is controlled by both the left and right hemispheres, the right brain plays a dominant role here. Zhang [27] via functional magnetic resonance imaging studies of event-related potentials showed that frontal-lobe activation in adult OSAS patients' decreased during executive tasks, especially in the right frontal lobe. Functional near-infrared spectroscopy studies [28] clearly revealed the process of the development of the prefrontal cortex in common attention mode: The activation area migrates gradually from the left Brodmann 9 area (BA9) of the infant to the left side BA9 + bilateral BA46 of the child, to the left side BA9 + bilateral BA46 + BA10 of the adult. From infancy to childhood to adulthood, the common attention process involves an increasing number of activations, and finally extends to the advanced cognitive area of the prefrontal cortex. Reviewing the above-mentioned documents, we find that the activations of children are different from those of adults. In the case of children aged 6–8 years, the left hemisphere plays a major role in attention and conflict tasks, which may be related to the progress of development from left to right. In this study, although there is no difference in ERP behavior between SDB and normal children, it is possible that behavioral abnormalities will develop in SDB with increased duration of illness.

CBCL was used to explore the behavioral problems of SDB children, and found that boys with SDB had hyperactivity, aggressivity, and internal behavior problems, whereas girls did not demonstrate such problems suggesting that boys may be more vulnerable

Table 6
Comparison of CBCL among the girls of two groups.

Group	Cases	Total Score	Depression	Withdrawn	Somatic complaints	Compulsion	Hyperactivity	Sexual Issues	Undiscipline	Aggression	Cruel
SDB	26	20(12,40.3)	4(2.0,8.25)	2.0(0.0,5.5)	1.0(0.00,4.0)	0.0(0,1.0)	4.0(2.0,6.5)	0.5(0.2.25)	0(0,1.0)	5(2.0,12.25)	0(0,1.0)
normal	26	18.5(15.8,35)	4(2.0,8.25)	2.5(1.0,5.0)	1.0(0,2.25)	1.0(0,1.25)	3.5(1.0, 6.0)	1.0(0,2.0)	0(0,1.0)	5.0(1.75,9.25)	0(0,1.00)
z		0.064	0.157	0.731	−0.797	0.934	−764	0.985	0.235	−0.266	−0.405
P		0.949	0.876	0.465	0.426	0.350	0.445	0.325	0.814	0.790	0.686

Table 7
Comparison of CBCL among the boys of two groups.

Groups	Cases	Total Score	Schizo	Depression	Poor Interpersonal	Compulsion	Somatic complains	Withdrawn	Hyperactivity	Aggression	Undiscipline
SDB	28	21 (15.3,32.3)	3 (2,5.0)	2.0(0,3.0)	1.0(1.0,2.0)	2.0(1.0,6.0)	1.0(0,2.8)	1.0(0,1.0)	4.0(2.0,5.0)	4.0 (4.0,8.0)	1.0(0,2.0)
normal	28	12 (8.3,19.5)	1.0 (0,2.0)	1.0(0,2.0)	1.0(0,2.0)	1.5(0.3,3.0)	0(0,1.0)	0(0,1.0)	2(1.0,4.0)	3.0 (2.0,6.8)	0(0.5,2.0) 0.166
z		−3.101	−3.339	−1.361	−1.084	−1.956	−2.340	−1.336	−2.559	−2.225	
P		0.002*	0.001*	0.174	0.278	0.050*	0.019*	0.182	0.011*	0.026*	0.868

Note: * $p < 0.05$.

to behavior problems. SDB is closely related to ADHD, having similar symptoms, affecting daily functions, social activities, and quality of life, and the two conditions can interact with each other [29]. A 4-year prospective study in Michigan showed that SDB is one cause of ADHD [30]. In this study, snoring and SDB symptoms were the main risk factors for the development or deterioration of ADHD and increased the risk of ADHD more than four times, especially in boys, similar to the results of our study. In children with OSAS, symptoms were relieved in 85% of the children after removing hypertrophic adenoids and tonsils [31]. Adenoidectomy can also significantly improve the symptoms of ADHD [32]. The destructive behavior of ADHD can cause such effects on night sleep, as insomnia, poor sleep quality, sleep struggling, and alterations in sleep-time segments; conversely, sleep disorders such as OSAS can cause daytime behavior problems similar to ADHD. Sleep disorders are common in children with ADHD, which may be due to a common neural pathway in the brain regions responsible for regulation and arousal [33]. Therefore, sleep apnea and ADHD may have some common physiological and pathological basis. SDB children show not only hyperactivity and inattention, but also aggression and bullying. The causes of aggressive behavior by children are complex, including sociological, biological, and cultural factors, but there is evidence that sleep is a major cause. A study conducted in public schools in an urban area showed that aggressive behavior by SDB children occurred at twice the frequency of normal children [34]. Snoring is not just an SDB symptoms, it also links SDB with aggressive behavior. It is also worth noting that insufficient sleep and insomnia are considered to be associated with adolescent suicide [35], and aggressive behavior in young children [36].

In conclusion, SDB children have conflict monitoring, attention, inhibition, and executive-function defects. The main impaired area of the brain was frontal region. The inhibitory function dysfunction may be one of the common childhood pathogeneses of both SDB and ADHD, two conditions which show some common clinical features. SDB can cause a series of behavioral problems, such as hyperactivity, aggression and the behavior problems of boys may be more obvious. Because the number size of our sample was small, the results need to be confirmed using a larger sample. SDB children in this study did not receive polysomnography studies, so the characteristics of cognitive impairment in SDB children of different sex and different severities of SDB need to be further studied.

Acknowledgments

The authors thank all the children and their parents who participated in this study, and the staff of the Children's Health Research Center.

There are no funders to report for this submission.

Appendix 1

Traditional Chinese version OSA-18 questionnaire.

OSA-18 total scores
Sleep disturbance:
1. Loud snoring 1 none 2 few 3 rare 4 sometimes 5 often 6 most 7 absolute
2. Breath holding/pauses 1 none 2 few 3 rare 4 sometimes 5 often 6 most 7 absolute
3. Choking or gasping 1 none 2 few 3 rare 4 sometimes 5often 6 most7absolute
4. Fragmented sleep 1 none 2 few 3 rare 4 sometimes 5often 6 most7absolute

Physical symptoms:
5. Mouth breathing 1 none 2 few 3 rare 4 sometimes 5 often 6 most 7 absolute
6. Frequent colds or 1 none 2 few 3 rare 4 sometimes 5 often 6 most 7 absolute

Upper respiratory tract infections (URIs)
7. Rhinorrhea 1 none 2 few 3 rare 4 sometimes 5 often 6 most 7 absolute
8. Dysphagia 1 none 2 few 3rare 4 sometimes 5 often 6 most 7 absolute

Emotional distress:
9. Mood swings or tantrums 1 none 2 few 3 rare 4 sometimes 5 often 6 most 7 absolute
10. Aggression/hyperactivity 1 none 2 few 3 rare 4 sometimes 5 often 6 most 7 absolute
11. Discipline problems 1 none 2 few 3 rare 4 sometimes 5 often 6 most 7 absolute

Daytime function:
12. Daytime drowsiness 1 none 2 few 3 rare 4 sometimes 5 often 6 most 7 absolute
13. Poor attention span 1 none 2 few 3 rare 4 sometimes 5 often 6 most 7 absolute
14. Difficulty awakening 1 none 2 few 3 rare 4 sometimes 5 often 6 most 7 absolute

Caregiver concerns:
15. Caregiver worried over 1 none 2 few 3 rare 4 sometimes 5 often 6 most 7 absolute

Child health
16. Caregiver concerned not 1 none 2 few 3 rare 4 sometimes 5 often 6 most 7 absolute

Enough air
17. Caregiver missed activities 1 none 2 few 3 rare 4 sometimes 5 often 6 most 7 absolute
18. Caregiver frustration 1 none 2 few 3 rare 4 sometimes 5 often 6 most 7 absolute

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