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ORIGINAL RESEARCH

A Comparative Investigation on Clinical Characteristics in Pediatric Obstructive Sleep Apnea Based on Two Distinct Guidelines

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Objective: To investigate the differences in assessment of clinical characteristics between children with obstructive sleep apnea (OSA) diagnosed according to the 2007 and 2020 guidelines and those without OSA, together with the relationships between polysomnography (PSG) parameters and cognitive tests scores in preschool and school-aged children with OSA.

Methods: Eighty children were totally recruited and divided into OSA and non-OSA groups based on two distinct guidelines, with further subclassification into preschool and school-aged subgroups. Differences in PSG parameters and cognitive tests scores between groups and subgroups were analyzed and compared, followed by partial correlation analysis to determine the correlations between these characteristics.

Results: Compared to the 2007 guideline, the 2020 guideline demonstrated more significant between-group differences in clinical characteristics assessments, especially verbal intelligent quotient (VIQ). For preschool children in the OSA and non-OSA subgroups, there were significant differences in PSG parameters and Block Diagram between the two guidelines. Additionally, the 2007 guideline showed difference in Picture Vocabulary, where the 2020 guideline exhibited differences in performance IQ (PIQ) and Geometric Figure For school-aged children in the OSA and non-OSA subgroups, both guidelines showed significant differences in PSG parameters, full-scale IQ (FIQ) and Block Diagram. The 2007 guideline had significant differences in PIQ, while the 2020 guideline had difference in VIQ. Furthermore, significant correlations were observed between PSG parameters and cognitive tests scores across different subgroups.

Conclusion: The 2020 guideline has advantages in assessing the clinical characteristics of children with OSA, especially for verbal function, and is worthy of clinical promotion and application.

Keywords: obstructive sleep apnea, children, guidelines, clinical characteristics

Introduction

Obstructive sleep apnea (OSA) is characterized by recurrent collapse of the upper airway during sleep, accompanied by repeated arousals (sleep fragmentation) or fluctuations in blood oxygen saturation (intermittent hypoxemia).[1,2] OSA is the most common sleep-disordered breathing (SDB) condition in children, with a prevalence rate ranging from 1.2% and 5.7%.[3] Age and obesity have been identified as high-risk factors influencing the disease severity of OSA.[4] Recently, several studies have provided valuable insights into the comorbidities associated with children with OSA,[5,6] especially cognitive dysfunction, which can affect multiple cognitive domains in children, such as attention, executive functions, visuospatial skills, and working memory. These impairments may be caused by sleep fragmentation and intermittent hypoxemia.[7–11] Given the neurodevelopmental immaturity of children with OSA, the resulting cognitive dysfunction may have far-reaching impacts on their physical and mental health.[8] Furthermore, the American Academy of Pediatrics (AAP)

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has also emphasized the importance of assessing cognitive function in children with OSA.[7] Therefore, while clinicians focus on improving the clinical symptoms of children with OSA, they need to pay close attention to the assessment of their cognitive dysfunction.

Currently, polysomnography (PSG) is recognized as the gold standard for diagnosing OSA in children, capable of accurately distinguishing between children with and without OSA, and detecting multiple quantitative clinical characteristic parameters related to sleep and respiratory events.[12] However, PSG cannot be widely applied due to its high technical threshold, low efficiency, high cost, limited patient acceptance, and significant regional variations in diagnostic and therapeutic capabilities. Therefore, new monitoring devices such as diaphragmatic ultrasound and portable watch are gradually being explored.[13] It is noteworthy that diagnostic criteria for pediatric OSA vary between China and other countries.[14–16] Specifically, the Urumqi draft, published in 2007, is based on the traditional concept of domestic expert consensus and is suitable for the Chinese pediatric population. It has been used in China for over a decade and recommends using an apnea hypopnea index (AHI) > 5 events/hour or obstructive apnea index (OAI) > 1 event/hour, along with minimal percutaneous oxygen saturation (minimal SpO_2) < 92% for diagnosing pediatric OSA.[14] With the development of sleep medicine and pediatrics, our experts have realized the lack of multidisciplinary evidence-based guidelines for diagnosing and treating pediatric OSA in China, making the formulation of such guidelines urgently needed to ensure scientific management of pediatric OSA. To meet this need, the first evidence-based guideline was published in 2020, adopting an obstructive apnea hypopnea index (OAHI) > 1 event/hour for diagnosing pediatric OSA,[15] which is similar to the third edition of the International Classification of Sleep Disorders (ICSD-3) updated in 2014.[16] Obviously, these are significant differences in diagnostic criteria between current domestic and international guidelines, especially considering that the diagnostic criteria for children with OSA in China have been updated twice in the past decade, which may have some potential impacts on the assessment of clinical characteristics, especially on the cognitive dysfunction.

Previous studies on cognitive dysfunction in children with OSA have relied on diverse guidelines, which may influence our accurate assessment of pediatric OSA. For example, Zhao Jing et al[17] used the Urumqi draft (AHI > 5 events/hour or OAI > 1 event/hour) and demonstrated adverse effects on cognitive function in children with mild or moderate OSA, especially preschool children (under 6 years old), compared to healthy controls. Shi Ye-wen[18] et al diagnosed children with OSA based on an OAHI ≥ 1 event/hour and included them in their study, and found that the serum neurofilament light (NfL) levels were elevated in the OSA group compared to the non-OSA group, and further demonstrated a significant correlation between NfL levels and cognitive tests scores in children with OSA. Additionally, a recent publication reported that researchers recruited children with OSA based on an OAHI > 1 event/hour, and they found that children with OSA had microstructural impairments in the left dentate gyrus compared to healthy controls, and these impairments were associated with poorer verbal learning and memory scores.[19] Considering that the Chinese most recent guideline for pediatric OSA was updated only in 2020, the potential impact of these two domestic guidelines (ie, the 2007 version and 2020 version) on the assessment of clinical characteristics in children with OSA remains unclear. Therefore, a comparative study is needed to clarify the differences between these two guidelines in assessing clinical characteristics between children with and without OSA.

In this context, we analyzed and compared the between-group differences in clinical characteristics (including PSG parameters and cognitive tests scores) between the OSA group and non-OSA group, classified according to the two domestic guidelines, respectively. Since the educational level of children in different age subgroups may influence the assessment of their cognitive function, to minimize this bias, we further divided the included participants into preschool subgroup and school-aged subgroup based on their educational level and explore the differences in these clinical characteristics among the subgroups. Finally, partial correlation analysis was conducted to investigate the correlations between PSG parameters and cognitive tests scores in children with OSA across different age subgroups.

Methods

Participants

Children aged 4 to 14 years old with suspected OSA were consecutively recruited from the sleep center at Beijing Children's Hospital (BCH) affiliated to Capital Medical University (CMU), along with healthy children with no history

of snoring who underwent routine physical examinations at our hospital's health center. A brief sleep questionnaire, namely the Pediatric Sleep Questionnaire (PSQ), was used for screening and as a comparison tool. A total of 80 children were included in the present study and divided into the OSA group (patient group) and the non-OSA group (control group) based on distinct guidelines (Figure 1). Specifically, the diagnostic criteria for OSA in 2007 guideline were an AHI > 5 events/hour or OAI > 1 event/hour, with a minimal SpO_2 < 92%. Among them, there were 38 children with OSA [5.0 (5.0, 7.0) years, 22 males] and 42 children without OSA [6.0 (5.0, 9.0) years, 21 males]. On the other hand, according to the 2020 diagnostic criteria for OSA, an OAHI > 1 event/hour was used, resulting in 55 children with OSA [5.0 (5.0, 8.0) years, 32 males] and 25 children without OSA [6.0 (5.0, 9.0) years, 11 males].

The 80 children were further divided into the preschool subgroup (4–5 years old) and the school-aged subgroup (6–14 years old) based on their educational level. According to the 2007 guideline, we obtained 19 children with OSA [5.0 (4.0, 5.0) years, 11 males] and 18 children without OSA [5.0 (4.0, 5.0) years, 8 males] in the preschool subgroup, and 19 children with OSA [7.0 (6.0, 11.0) years, 11 males] and 24 children without OSA [9.0 (7.0, 10.7) years, 13 males] in the school-aged subgroup. According to the 2020 guideline, we obtained 28 children with OSA [5.0 (4.0, 5.0) years, 15 males] and 9 children without OSA [5.0 (4.0, 5.0) years, 4 males] in the preschool subgroup, and 27 children with OSA [8.0 (6.0, 11.0) years, 17 males] and 16 children without OSA [9.0 (6.2, 10.0) years, 7 males] in the school-aged subgroup. The protocol of the present study was approved by the Medical Ethics Committee of BCH, and the informed consent forms (ICFs) were signed by the guardians of all participants.

The inclusion criteria for all participants in this study were: (1) aged 4–14 years; (2) diagnosed with OSA by PSG according to two distinct guidelines (the 2007 and the 2020 versions); (3) healthy children with no history of snoring. The exclusion criteria were as follows: (1) presence of other sleep disorders, such as central sleep apnea, and primary snoring; (2) previous intervention for OSA (eg, surgery or medication); (3) neurological or psychiatric disorders, such as epilepsy, intracranial tumors, depression, and attention deficit hyperactivity disorder, etc.; (4) inability to cooperate with cognitive function assessments.

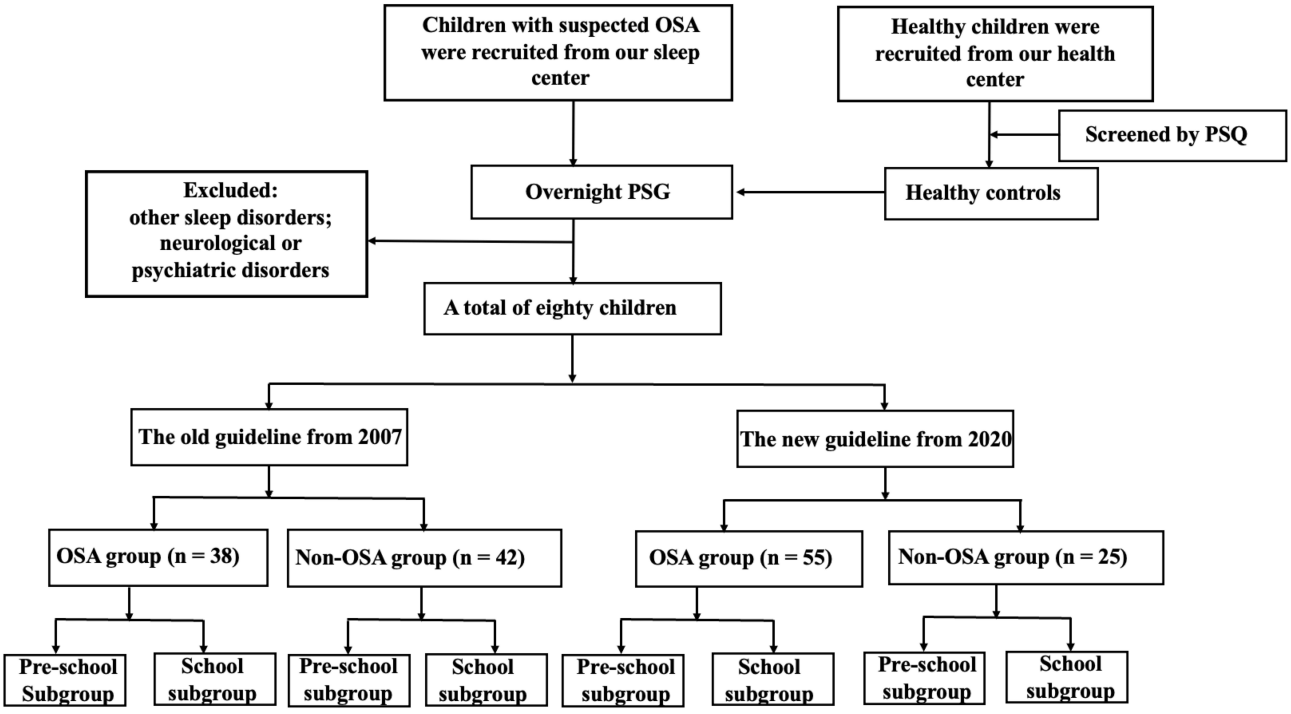

Figure 1 The flowchart of screening participants for this study.
Abbreviations: PSG, polysomnography; PSQ, Pediatric Sleep Questionnaire.

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Nocturnal PSG

Each participant underwent nocturnal PSG in an individual room at the BCH sleep center, where a guardian accompanied the child throughout the night. During the 8 hours overnight monitoring, conventional electrical activities and sleep-related parameters were recorded by the Alice 5 Diagnostic Sleep System (Respironics, USA). The following day, specialized technicians collected and analyzed the monitoring data of all participants according to the sleep scoring manual of the American Academy of Sleep Medicine (AASM).[20] Sleep reports were generated, outlining sleep indices and changes in levels of percutaneous oxygen saturation. The main PSG parameters such as OAHI, AHI, OAI, hypopnea index (HI), oxygen desaturation index (ODI), minimal SpO_2, sleep efficiency (SE), and arousal index (AI) were recorded to differentiate between the OSA group and the non-OSA group.

Assessment of Cognitive Function

In the present study, the assessment of cognitive function for the enrolled children was conducted during the daytime after the completion of PSG. The Wechsler Intelligence Scale for Children (WISC) is widely used globally to measure comprehensive and general cognitive function in pediatric population. It comprises two subscales: the verbal test and the performance test.[21] The former assesses pediatric abstract reasoning ability, attention, and short-term memory function, while the latter assesses their perceptual reasoning abilities, visual recognition abilities, and motor coordination skills.[22,23] Given the competency and universality of WISC,[17,21] the present study employed the Chinese Wechsler Younger Children Scale of Intelligence (C-WYCSI) and Chinese WISC (C-WISC) to assess cognitive function in participants aged 4 to 5 years and 6 to 14 years, respectively. The C-WYCSI includes five verbal subtests (Information, Picture Vocabulary, Arithmetic, Picture Summary, and Comprehension) and six performance subtests (Animal Deposit, Picture Completion, Maze, Visual Analysis, Block Diagram, and Geometric Figure).[24] The C-WISC consists of six verbal subtests (Information, Similarities, Arithmetic, Vocabulary, Comprehension, and Digital Span) and five performance subtests (Picture Completion, Picture Arrangement, Block Diagram, Object Assembly, and Code).[25] All participants, accompanied by their parents, completed the cognitive function assessment under the guidance of an intelligence testing technician from psychometric department. The results were calculated and categorized into three scores: full-scale intelligent quotient (FIQ), verbal IQ (VIQ), and performance IQ (PIQ).

Statistical Analyses

Continuous variables for the OSA group and the non-OSA group (as well as the preschool subgroup and the school-aged subgroup) were described as mean ± standard deviation (Mean ± SD) or median (P25, P75). Normally distributed variables and non-normally distributed variables between two groups were compared using the two-sample *t*-test or Mann–Whitney *U*-test, respectively. Categorical variables (ie, gender and education) were described as proportions and compared using the χ^2 test. All statistical analyses of clinical data were conducted using IBM SPSS software (version 25.0, Chicago, IL, USA). A two-tailed P value < 0.05 was considered the significant statistical threshold.

Additionally, based on two distinct guidelines, partial correlation analysis was performed to examine the relationships between PSG parameters and cognitive tests scores in the preschool subgroup and school-aged subgroup of children with OSA. Specifically, for both subgroups, the correlations between each of PSG parameters (ie, OAHI, AHI, OAI, HI, ODI, minimal SpO_2, SE, and AI) and cognitive tests scores were analyzed using SPSS, with the age, gender, and body mass index (BMI) as uninterested covariate. The statistical threshold was set at $P < 0.05$.

Results

Demographic and Clinical Information

Tables 1 and 2 summarized the demographics and clinical characteristics of the OSA group and the non-OSA group based on two distinct guidelines, respectively. Although these two tables showed no significant differences between the OSA and non-OSA groups in terms of age, gender, education, BMI, and SE, these were between-group differences in PSG parameters such as OAHI, AHI, OAI, HI, ODI, minimal SpO_2, and AI between children with OSA and those without. Additionally, there were significant differences in FIQ, VIQ and PIQ scores between the two groups classified

Table 1 Demographic and Clinical Characteristics for OSA Group and Non-OSA Group Classified by the 2007 Guideline

	OSA (N = 38)	Non-OSA (N = 42)	t/χ^2 /z value	*P* value
Age (years)	5.5 (5.0, 7.0)	6.0 (5.0, 9.0)	− 1.024	0.306
Gender			0.500	0.479
Male	22 (58%)	21 (50%)		
Female	16 (42%)	21 (50%)		
Education			0.409	0.522
Preschool	19 (50%)	18 (43%)		
School	19 (50%)	24 (57%)		
BMI (kg/m^2)	17.4 (15.0, 20.8)	15.8 (14.6, 19.4)	− 1.089	0.276
OAHI (events/h)	7.4 (4.8, 15.2)	0.9 (0.4, 1.7)	− 6.786	< 0.001*
AHI (events/h)	9.4 (6.4, 18.6)	1.6 (0.7, 2.6)	− 7.555	< 0.001*
OAI (events/h)	2.7 (1.0, 5.6)	0.0 (0.0, 0.1)	− 6.492	< 0.001*
HI (events/h)	5.4 (3.2, 13.8)	0.9 (0.4, 1.8)	− 6.447	< 0.001*
ODI (events/h)	2.9 (0.5, 6.5)	0.0 (0.0, 0.3)	− 5.491	< 0.001*
Minimal SpO_2 (%)	86.5 (82.7, 90.0)	93.0 (90.0, 95.2)	− 5.288	< 0.001*
AI (events/h)	5.0 (2.4, 9.7)	1.9 (0.6, 2.5)	− 5.393	< 0.001*
SE (%)	88.1 (80.0, 90.5)	85.9 (80.4, 91.2)	0217	0.828
FIQ (scores)	96.9 ± 9.1	102.4 ± 8.3	− 2.818	0006*
VIQ (scores)	96.5 ± 9.6	100.7 ± 9.5	− 1.950	0055
PIQ (scores)	97.6 ± 10.3	103.8 ± 10.2	− 2.670	0.009*

Note: *P** < 0.05.

Abbreviations: BMI, body mass index; OAHI, obstructive apnea hypopnea index; AHI, apnea hypopnea index; OAI, obstructive apnea index; HI, hypopnea index; ODI, oxygen desaturation index; Minimal SpO_2, minimal percutaneous oxygen saturation; AI, arousal index; SE, sleep efficiency; FIQ, full-scale intelligent quotient; VIQ, verbal intelligent quotient; PIQ, performance intelligent quotient.

Table 2 Demographic and Clinical Characteristics for OSA Group and Non-OSA Group Classified by the 2020 Guideline

	OSA (N = 55)	Non-OSA (N = 25)	t/χ^2 /z value	*P* value
Age (years)	5.0 (5.0, 8.0)	6.0 (5.0, 9.0)	− 1.177	0.239
Gender			1.391	0.238
Male	32 (58%)	11 (44%)		
Female	23 (42%)	14 (56%)		
Education			1.537	0.215
Preschool	28 (51%)	9 (36%)		
School	27 (49%)	16 (64%)		
BMI (kg/m^2)	17.2 (14.8, 20.1)	15.9 (14.5, 19.3)	− 0.779	0.436
OAHI (events/h)	5.1 (1.7, 11.5)	0.5 (0.2, 0.8)	− 7.140	< 0.001*
AHI (events/h)	6.9 (3.0, 12.7)	0.9 (0.5, 1.4)	− 6.696	< 0.001*
OAI (events/h)	1.1 (0.1, 3.4)	0.0 (0.0, 0.2)	− 3.949	< 0.001*
HI (events/h)	4.0 (1.9, 9.0)	0.4 (0.2, 0.7)	− 6.816	< 0.001*
ODI (events/h)	1.0 (0.0, 4.2)	0.0 (0.0, 0.3)	− 3.793	< 0.001*
Minimal SpO_2 (%)	89.0 (84.0, 92.0)	93.0 (90.0, 96.0)	− 3.387	< 0.001*
AI (events/h)	3.0 (2.0, 7.1)	0.8 (0.3, 2.1)	− 5.265	< 0.001*
SE (%)	86.0 (79.1, 91.7)	87.0 (82.5, 90.6)	− 0.260	0.795
FIQ (scores)	97.9 ± 8.9	103.9 ± 8.1	− 2.852	0.006*
VIQ (scores)	97.0 ± 8.8	102.5 ± 10.6	− 2.427	0.018*
PIQ (scores)	99.1 ± 11.1	104.6 ± 8.5	− 2.194	0.031*

Note: *P** < 0.05.

Abbreviations: BMI, body mass index; OAHI, obstructive apnea hypopnea index; AHI, apnea hypopnea index; OAI, obstructive apnea index; HI, hypopnea index; ODI, oxygen desaturation index; Minimal SpO_2, minimal percutaneous oxygen saturation; AI, arousal index; SE, sleep efficiency; FIQ, full-scale intelligent quotient; VIQ, verbal intelligent quotient; PIQ, performance intelligent quotient.

according to the 2020 guideline, while significant differences in FIQ and PIQ scores were observed between two groups classified according to the 2007 guideline.

Further dividing the preschool subgroup and school-aged subgroup based on the educational level, we found that in both subgroups, children diagnosed with OSA according to the 2007 guideline had higher values for most PSG parameters (ie, OAHI, AHI, OAI, HI, ODI, and AI) compared to children without OSA, while the children with OSA showed lower levels of minimal SpO_2 and lower scores on several cognitive tests (ie, lower Picture Vocabulary and Block Diagram in the preschool subgroup; lower FIQ, PIQ, and Block Diagram in the school-aged subgroup). The results were showed in Tables 3 and 4. Similarly, we also found that in both subgroups, children diagnosed with OSA according to the 2020 guideline had higher values for most PSG parameters (ie, OAHI, AHI, OAI, HI, ODI, and AI) compared to children without OSA, while the children with OSA showed lower levels of minimal SpO_2 and lower scores on several cognitive tests (ie, lower PIQ, Block Diagram, and Geometric Figure in the preschool subgroup; lower FIQ, VIQ, and Block Diagram in the school-aged subgroup). The results were showed in Tables 5 and 6.

Partial Correlation Analysis Between the PSG Parameters and Cognitive Tests Scores

Partial correlation analysis showed significant correlations between PSG parameters and multiple cognitive tests scores (ie, verbal subtests and performance subtests) in both preschool subgroup and school-aged subgroup across distinct

Table 3 Demographic and Clinical Characteristics for OSA and Non-OSA in the Preschool Subgroup Classified by the 2007 Guideline

	OSA (N = 19)	Non-OSA (N = 18)	t/χ^2 /z value	*P* value
Age (years)	5.0 (4.0, 5.0)	5.0 (4.0, 5.0)	− 0.142	0.887
Gender			0.669	0.413
Male	11 (58%)	8 (44%)		
Female	8 (42%)	10 (56%)		
BMI (kg/m^2)	15.5 (14.1, 17.7)	15.6 (14.5, 16.6)	− 0.106	0.915
OAHI (events/h)	6.8 (4.9, 15.9)	1.0 (0.7, 2.0)	− 4.985	< 0.001*
AHI (events/h)	9.2 (6.4, 18.6)	1.8 (0.9, 2.9)	− 5.106	< 0.001*
OAI (events/h)	3.3 (0.9, 6.8)	0.0 (0.0, 0.2)	− 4.274	< 0.001*
HI (events/h)	4.9 (3.2, 9.6)	1.3 (0.7, 2.6)	− 4.179	< 0.001*
ODI (events/h)	2.8 (0.6, 7.2)	0.2 (0.0, 0.5)	− 3.516	< 0.001*
Minimal SpO_2 (%)	87.0 (82.0, 91.0)	93.0 (90.5, 95.2)	− 3.981	< 0.001*
AI (events/h)	5.1 (2.0, 9.6)	1.9 (1.0, 2.6)	− 3.467	< 0.001*
SE (%)	89.2 (81.0, 94.9)	87.1 (83.1, 93.9)	− 0.061	0.952
FIQ (scores)	97.2 ± 10.9	102.3 ± 9.0	− 1.534	0.134
VIQ (scores)	95.2 ± 11.0	99.2 ± 11.9	− 1.060	0.296
Information	8.2 ± 2.1	8.6 ± 3.5	− 0.418	0.679
Picture Vocabulary	12.0 (11.0, 13.0)	13.0 (12.7, 14.0)	− 2.290	0.022*
Arithmetic	10.7 ± 1.8	10.6 ± 1.8	0.201	0.842
Picture Summary	9.8 ± 2.9	10.5 ± 2.5	− 0.738	0.465
Comprehension	6.9 ± 2.3	6.9 ± 3.0	− 0.056	0.955
PIQ (scores)	99.6 ± 11.9	105.2 ± 8.7	− 1.599	0.119
Animal Deposit	11.0 (10.0, 13.0)	12.0 (10.0, 13.0)	− 0.606	0.545
Picture Completion	8.1 ± 3.2	7.9 ± 2.6	0.166	0.806
Maze	10.0 (7.0, 14.0)	14.0 (10.0, 14.0)	− 1.302	0.193
Visual Analysis	9.2 ± 3.2	9.5 ± 2.4	− 0.360	0.721
Block Diagram	10.0 (10.0, 13.0)	13.0 (11.7, 14.0)	− 2.264	0.024*
Geometric Figure	10.0 ± 1.8	10.7 ± 1.2	− 1.406	0.169

Note: *P** < 0.05.

Abbreviations: BMI, body mass index; OAHI, obstructive apnea hypopnea index; AHI, apnea hypopnea index; OAI, obstructive apnea index; HI, hypopnea index; ODI, oxygen desaturation index; Minimal SpO_2, minimal percutaneous oxygen saturation; AI, arousal index; SE, sleep efficiency; FIQ, full-scale intelligent quotient; VIQ, verbal intelligent quotient; PIQ, performance intelligent quotient.

Table 4 Demographic and Clinical Characteristics for OSA and Non-OSA in the School-Aged Subgroup Classified by the 2007 Guideline

	OSA (N = 19)	Non-OSA (N = 24)	t/χ^2 /z value	*P* value
Age (years)	7.0 (6.0, 11.0)	9.0 (7.0, 10.7)	− 1.290	0.197
Gender			0.060	0.807
Male	11 (58%)	13 (54%)		
Female	8 (42%)	11 (46%)		
BMI (kg/m^2)	21.0 ± 5.8	18.1 ± 4.0	1.911	0.063
OAHI (events/h)	8.8 (2.9, 15.0)	0.9 (0.3, 1.6)	− 4.579	< 0.001*
AHI (events/h)	9.8 (7.1, 19.3)	1.1 (0.7, 1.9)	− 5.492	< 0.001*
OAI (events/h)	2.6 (1.1, 5.0)	0.0 (0.0, 0.1)	− 4.790	< 0.001*
HI (events/h)	5.5 (3.2, 17.0)	0.6 (0.3, 1.6)	− 4.761	< 0.001*
ODI (events/h)	3.0 (0.1, 4.6)	0.0 (0.0, 0.1)	− 4.219	< 0.001*
Minimal SpO_2 (%)	86.0 (84.0, 89.0)	92.0 (90.0, 95.5)	− 3.593	< 0.001*
AI (events/h)	3.9 (2.6, 12.5)	1.6 (0.6, 2.3)	− 4.221	< 0.001*
SE (%)	82.6 (78.3, 89.7)	84.3 (75.8, 89.5)	0.000	1.000
FIQ (scores)	96.6 ± 7.3	102.5 ± 7.8	− 2.516	0.016*
VIQ (scores)	97.9 ± 8.1	101.8 ± 7.2	− 1.695	0.098
Information	8.0 (7.0, 10.0)	9.0 (7.0, 10.0)	− 1.198	0.231
Similarities	11.0 (8.0, 12.0)	11.0 (10.0, 12.0)	− 0.552	0.581
Arithmetic	11.0 (9.0, 12.0)	10.0 (10.0, 11.0)	− 0.745	0.456
Vocabulary	9.0 (8.0, 10.0)	9.0 (7.0, 14.0)	− 0.982	0.326
Comprehension	10.0 (9.0, 11.0)	10.0 (10.0, 11.0)	− 0.964	0.335
Digital Span	10.0 (9.0, 11.0)	10.0 (10.0, 11.0)	−1.881	0.060
PIQ (scores)	95.6 ± 8.1	102.7 ±11.2	− 2.388	0.022*
Picture Completion	8.0 (6.0, 9.0)	7.5 (6.0, 8.0)	− 0.693	0.488
Picture Arrangement	9.0 (8.0, 11.0)	10.0 (9.0, 12.0)	− 1.720	0.085
Block Diagram	10.2 ± 3.0	13.3 ± 4.0	− 2.859	0.007*
Object Assembly	11.0 (10.0,12.0)	12.0 (11.0, 12.0)	− 0.915	0.360
Code	9.0 (7.0, 11.0)	9.0 (7.2, 12.0)	− 0.936	0.349

Note: *P** < 0.05.

Abbreviations: BMI, body mass index; OAHI, obstructive apnea hypopnea index; AHI, apnea hypopnea index; OAI, obstructive apnea index; HI, hypopnea index; ODI, oxygen desaturation index; Minimal SpO_2, minimal percutaneous oxygen saturation; AI, arousal index; SE, sleep efficiency; FIQ, full-scale intelligent quotient; VIQ, verbal intelligent quotient; PIQ, performance intelligent quotient.

Table 5 Demographic and Clinical Characteristics for OSA and Non-OSA in the Preschool Subgroup Classified by the 2020 Guideline

	OSA (N = 28)	Non-OSA (N = 9)	t/χ^2 /z value	*P* value
Age (years)	5.0 (4.0, 5.0)	5.0 (4.0, 5.0)	− 0.082	0.934
Gender			0.227	0.634
Male	15 (54%)	4 (44%)		
Female	13 (46%)	5 (56%)		
BMI (kg/m^2)	15.6 ± 1.9	16.5 ± 2.0	− 1.181	0.246
OAHI (events/h)	5.1 (2.7, 10.6)	0.7 (0.5, 0.8)	− 4.462	< 0.001*
AHI (events/h)	6.4 (3.8, 11.4)	1.0 (0.5, 1.5)	− 4.426	< 0.001*
OAI (events/h)	1.2 (0.1, 5.0)	0.0 (0.0, 0.1)	− 3.020	0.003*
HI (events/h)	4.0 (2.8, 8.5)	0.8 (0.5, 1.3)	− 4.019	< 0.001*
ODI (events/h)	1.0 (0.4, 6.0)	0.2 (0.0, 0.5)	− 2.671	0.008*
Minimal SpO_2 (%)	89.0 (84.0, 93.0)	93.0 (91.5, 96.0)	− 2.523	0.012*
AI (events/h)	3.8 (2.0, 6.7)	1.2 (0.4, 1.9)	− 3.525	< 0.001*

(*Continued*)

Table 5 (Continued).

	OSA (N = 28)	Non-OSA (N = 9)	t/χ^2 /z value	*P* value
SE (%)	89.2 (81.0, 94.9)	87.0 (83.4, 92.8)	− 0.637	0.524
FIQ (scores)	97.9 ± 9.7	105.4 ± 10.3	− 2.004	0.053
VIQ (scores)	95.7 ± 10.2	101.4 ± 14.8	− 1.294	0.204
Information	8.3 ± 2.3	8.7 ± 4.3	− 0.441	0.662
Picture Vocabulary	12.0 (11.0, 14.0)	14.0 (12.5, 14.0)	− 1.542	0.123
Arithmetic	10.5 ± 1.6	11.3 ± 2.2	− 1.139	0.263
Picture Summary	10.0 ± 2.7	10.6 ± 2.8	− 0.641	0.526
Comprehension	6.8 ± 2.4	7.2 ± 3.4	− 0.390	0.699
PIQ (scores)	100.2 ± 11.1	108.8 ± 6.2	− 2.195	0.035*
Animal Deposit	11.0 (10.0, 13.0)	12.0 (10.0, 13.0)	− 0.199	0.842
Picture Completion	7.9 ± 3.2	8.3 ± 1.8	− 0.360	0.721
Maze	11.2 ± 3.7	12.8 ± 2.3	− 1.607	0.122
Visual Analysis	9.0 ± 2.9	10.5 ± 2.4	− 1.430	0.162
Block Diagram	11.3 ± 2.0	13.4 ± 1.0	− 4.165	< 0.001*
Geometric Figure	10.1 ±1.7	11.3 ± 0.8	− 2.062	0.047*

Note: *P** < 0.05.

Abbreviations: BMI, body mass index; OAHI, obstructive apnea hypopnea index; AHI, apnea hypopnea index; OAI, obstructive apnea index; HI, hypopnea index; ODI, oxygen desaturation index; Minimal SpO_2, minimal percutaneous oxygen saturation; AI, arousal index; SE, sleep efficiency; FIQ, full-scale intelligent quotient; VIQ, verbal intelligent quotient; PIQ, performance intelligent quotient.

Table 6 Demographic and Clinical Characteristics for OSA and Non-OSA in the School-Aged Subgroup Classified by the 2020 Guideline

	OSA (N = 27)	Non-OSA (N = 16)	t/χ^2 /z value	*P* value
Age (years)	8.0 (6.0, 11.0)	9.0 (6.2, 10.0)	− 0.283	0.777
Gender			1.504	0.220
Male	17 (63%)	7 (44%)		
Female	10 (37%)	9 (56%)		
BMI (kg/m^2)	19.8 (16.4, 22.2)	15.7 (13.6, 21.8)	− 1.885	0.059
OAHI (events/h)	5.7 (1.7, 12.2)	0.3 (0.2, 0.8)	− 5.434	< 0.001*
AHI (events/h)	7.8 (2.9, 12.8)	0.8 (0.4, 1.1)	− 4.901	< 0.001*
OAI (events/h)	1.1 (0.0, 3.0)	0.0 (0.0, 0.3)	− 2.506	0.012*
HI (events/h)	4.0 (1.7, 10.1)	0.3 (0.1, 0.4)	− 5.394	< 0.001*
ODI (events/h)	0.5 (0.0, 4.2)	0.0 (0.0, 0.2)	− 2.390	0.017*
Minimal SpO_2 (%)	89.0 (84.0, 92.0)	92.5 (90.0, 95.5)	− 2.344	0.019*
AI (events/h)	3.0 (2.2, 7.2)	0.7 (0.2, 2.1)	− 3.972	< 0.001*
SE (%)	82.4 (77.7, 89.3)	86.4 (81.1, 90.4)	− 1.232	0.218
FIQ (scores)	98.0 ± 8.3	103.1 ± 6.8	− 2.068	0.046*
VIQ (scores)	98.3 ± 7.3	103.2 ± 7.9	− 2.058	0.046*
Information	8.0 (7.0, 9.0)	9.0 (7.0, 10.7)	− 1.948	0.051
Similarities	11.0 (10.0, 12.0)	11.0 (10.0, 12.0)	− 0.901	0.367
Arithmetic	11.0 (9.0, 12.0)	10.5 (10.0, 11.0)	− 0.115	0.909
Vocabulary	9.0 (8.0, 10.0)	9.5 (7.0, 14.0)	− 0.690	0.490
Comprehension	10.0 (9.0, 11.0)	10.0 (10.0, 11.0)	− 0.386	0.700
Digital Span	10.0 (9.0, 11.0)	11.0 (10.0, 11.0)	− 1.774	0.076
PIQ (scores)	98.0 ± 11.1	102.3 ± 8.9	− 1.302	0.200
Picture Completion	8.0 (6.0, 9.0)	7.5 (6.0, 8.0)	− 1.152	0.249
Picture Arrangement	10.0 (8.0, 11.0)	10.0 (9.0, 11.0)	− 0.320	0.749

(*Continued*)

Table 6 (Continued).

	OSA (N = 27)	Non-OSA (N = 16)	t/χ^2 /z value	*P* value
Block Diagram	11.0 ± 3.7	13.5 ± 3.7	− 2.045	0.047*
Object Assembly	12.0 (10.0, 12.0)	11.0 (11.0, 12.0)	− 0.248	0.804
Code	9.0 (7.0, 11.0)	9.0 (8.2, 11.7)	− 0.923	0.356

Note: *P** < 0.05.

Abbreviations: BMI, body mass index; OAHI, obstructive apnea hypopnea index; AHI, apnea hypopnea index; OAI, obstructive apnea index; HI, hypopnea index; ODI, oxygen desaturation index; Minimal SpO_2, minimal percutaneous oxygen saturation; AI, arousal index; SE, sleep efficiency; FIQ, full-scale intelligent quotient; VIQ, verbal intelligent quotient; PIQ, performance intelligent quotient.

guidelines. For preschool children diagnosed with OSA according to the 2007 guideline, the AHI (r = 0.532, P = 0.041), HI (r = 0.644, P = 0.010), and ODI (r = 0.632, P = 0.011) were significantly positively correlated with the score of VIQ. The HI (r = 0.636, P = 0.011) and ODI (r = 0.571, P = 0.026) were positively correlated with the score of Information. The HI was positively correlated with the score of Picture Summary (r = 0.651, P = 0.009). Additionally, the AHI (r = 0.592, P = 0.020), HI (r = 0.565, P = 0.028), ODI (r = 0.626, P = 0.013), and AI (r = 0.522, P = 0.046) were positively correlated with the score of Comprehension, respectively. For the preschool children diagnosed with OSA according to the 2020 guideline, the HI and ODI were positively correlated with the scores of VIQ (HI: r = 0.470, P = 0.021; ODI: r = 0.496, P = 0.014) and Picture Summary (HI: r = 0.501, P = 0.013; ODI: r = 0.410, P = 0.047), respectively (Table 7).

For the school-aged children diagnosed with OSA according to the 2007 guideline, the SE was significantly negatively correlated with the score of Digital Span (r = - 0.568, P = 0.022), and the AI was negatively correlated with the score of Picture Completion (r = - 0.501, P = 0.048). Whereas the ODI (r = 0.540, P = 0.031) and AI (r = 0.613, P = 0.012) were significantly positively correlated with the score of Block Diagram. For the school-aged children diagnosed with OSA according to the 2020 guideline, the SE was negatively correlated with the score of Digital Span (r = - 0.418, P = 0.047). Additionally, the OAHI (r = - 0.429, P = 0.041), AHI (r = - 0.435, P = 0.038), OAI (r = - 0.447,

Table 7 Correlation Between the Sleep Parameters and Cognitive Tests Scores in the Preschool Subgroup Classified by These Two Guidelines

	OAHI	AHI	OAI	HI	ODI	Minimal SpO_2	SE	AI
The 2007 version								
FIQ (scores)	r = 0.270	r = 0.278	r = 0.124	r = 0.458	r = 0.453	r = - 0.186	r = 0.288	r = 0.271
VIQ (scores)	r = 0.495	r = 0.532*	r = 0.310	r = 0.644*	r = 0.632*	r = - 0.293	r = 0.186	r = 0.406
Information	r = 0.446	r = 0.471	r = 0.254	r = 0.636*	r = 0.571*	r = - 0.280	r = 0.380	r = 0.327
Picture Summary	r = 0.465	r = 0.475	r = 0.195	r = 0.651*	r = 0.482	r = - 0.245	r = 0.131	r = 0.387
Comprehension	r = 0.499	r = 0.592*	r = 0.441	r = 0.565*	r = 0.626*	r = - 0.326	r = 0.114	r = 0.522*
PIQ (scores)	r = - 0.010	r = - 0.031	r = - 0.095	r = 0.184	r = 0.169	r = - 0.046	r = 0.325	r = 0.082
The 2020 version								
FIQ (scores)	r = 0.204	r = 0.200	r = 0.076	r = 0.365	r = 0.359	r = - 0.139	r = 0.237	r = 0.191
VIQ (scores)	r = 0.350	r = 0.364	r = 0.213	r = 0.470*	r = 0.496*	r = - 0.180	r = 0.007	r = 0.276
Information	r = 0.215	r = 0.227	r = 0.123	r = 0.334	r = 0.367	r = - 0.139	r = 0.028	r = 0.118
Picture Summary	r = 0.351	r = 0.342	r = 0.154	r = 0.501*	r = 0.410*	r = - 0.158	r = 0.105	r = 0.294
Comprehension	r = 0.322	r = 0.373	r = 0.278	r = 0.364	r = 0.392	r = - 0.158	r = - 0.155	r = 0.366
PIQ (scores)	r = 0.007	r = - 0.012	r = - 0.083	r = 0.166	r = 0.119	r = - 0.071	r = 0.388	r = 0.054

Note: *r* * was considered statistically significant.

Abbreviations: OAHI, obstructive apnea hypopnea index; AHI, apnea hypopnea index; OAI, obstructive apnea index; HI, hypopnea index; ODI, oxygen desaturation index; Minimal SpO_2, minimal percutaneous oxygen saturation; SE, sleep efficiency; AI, arousal index; FIQ, full-scale intelligent quotient; VIQ, verbal intelligent quotient; PIQ, performance intelligent quotient.

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Table 8 Correlation Between the Sleep Parameters and Cognitive Tests Scores in the School-Aged Subgroup Classified by These Two Guidelines

	OAHI	AHI	OAI	HI	ODI	Minimal SpO_2	SE	AI
The 2007 version								
FIQ (scores)	*r* = 0.170	*r* = 0.165	*r* = 0.197	*r* = 0.174	*r* = 0.389	*r* = 0.011	*r* = - 0.456	*r* = 0.361
VIQ (scores)	*r* = 0.082	*r* = 0.069	*r* = 0.033	*r* = 0.079	*r* = 0.237	*r* = - 0.037	*r* = - 0.301	*r* = 0.176
Digital Span	*r* = - 0.029	*r* = - 0.032	*r* = - 0.054	*r* = - 0.014	*r* = 0.207	*r* = 0.208	*r* = - 0.568*	*r* = 0.130
PIQ (scores)	*r* = 0.214	*r* = 0.221	*r* = 0.304	*r* = 0.228	*r* = 0.404	*r* = 0.050	*r* = - 0.378	*r* = 0.437
Picture Completion	*r* = - 0.495	*r* = - 0.497	*r* = - 0.405	*r* = - 0.485	*r* = - 0.427	*r* = 0.498	*r* = 0.194	*r* = - 0.501*
Block Diagram	*r* = 0.425	*r* = 0.443	*r* = 0.448	*r* = 0.423	*r* = 0.540*	*r* = - 0.132	*r* = - 0.387	*r* = 0.613*
The 2007 version								
FIQ (scores)	*r* = 0.033	*r* = 0.011	*r* = 0.019	*r* = 0.034	*r* = 0.228	*r* = 0.157	*r* = - 0.322	*r* = 0.162
VIQ (scores)	*r* = 0.062	*r* = 0.046	*r* = 0.083	*r* = 0.049	*r* = 0.221	*r* = - 0.013	*r* = - 0.207	*r* = 0.135
Digital Span	*r* = - 0.083	*r* = - 0.094	*r* = - 0.087	*r* = - 0.078	*r* = 0.184	*r* = 0.249	*r* = - 0.418*	*r* = 0.071
PIQ (scores)	*r* = 0.011	*r* = - 0.009	*r* = - 0.042	*r* = 0.025	*r* = 0.164	*r* = 0.235	*r* = - 0.284	*r* = 0.142
Picture Completion	*r* = - 0.429*	*r* = - 0.435*	*r* = - 0.447*	*r* = - 0.408	*r* = - 0.391	*r* = 0. 476*	*r* = - 0.001	*r* = - 0.448*
Block Diagram	*r* = 0.228	*r* = 0.211	*r* = 0.183	*r* = 0.217	*r* = 0.388	*r* = 0.030	*r* = - 0.229	*r* = 0.371

Note: *r** was considered statistically significant.
Abbreviations: OAHI, obstructive apnea hypopnea index; AHI, apnea hypopnea index; OAI, obstructive apnea index; HI, hypopnea index; ODI, oxygen desaturation index; Minimal SpO_2, minimal percutaneous oxygen saturation; SE, sleep efficiency; AI, arousal index; FIQ, full-scale intelligent quotient; VIQ, verbal intelligent quotient; PIQ, performance intelligent quotient.

$P = 0.033$), and AI ($r = -0.448$, $P = 0.032$) were negatively correlated with the score of Picture Completion, while the minimal SpO_2 was positively correlated with the score of Picture Completion ($r = 0.476$, $P = 0.022$) (Table 8).

Discussion

The purposes of the present study were to explore the differences in assessment of clinical characteristics between children with OSA and those without OSA diagnosed based on two distinct guidelines, and to investigate the relationships between PSG parameters and cognitive tests scores in preschool and school-aged children with OSA. To this end, we compared the PSG parameters and cognitive tests scores of children with OSA and those without OSA divided by two distinct guidelines, and conducted subgroup analyses to determine the between-subgroup differences between the preschool subgroup and the school-aged subgroup. Partial correlation analysis was then performed to determine the correlations between these sleep parameters and cognitive tests scores in children with OSA across different age subgroups. We not only found that the diagnostic criteria of the 2020 guideline exhibited more significant intergroup and inter-subgroup differences in assessment of cognitive dysfunction, especially in verbal function. Additionally, we observed significant correlations between these PSG parameters and cognitive tests scores across different age subgroups. To our knowledge, the present study is the first comparative research to investigate the differences in assessing cognitive dysfunction in children with OSA based on these two guidelines.

Pediatric OSA is an independent disease, with the most common cause being adenoidal and (or) tonsillar hypertrophy, manifesting as recurrent upper airway obstruction.[7,26] In diagnosing pediatric OSA, distinct guidelines may vary in measuring clinical disease characteristics such as sleep fragmentation and intermittent hypoxemia, which are important mechanism-related factors in revealing cognitive dysfunction.[2,10,27] In the present study, we applied two guidelines for diagnosing OSA: the 2007 version and the 2020 version. The diagnostic criteria for children with OSA in the 2007 guideline used an AHI > 5 events/hour or OAI > 1 event/hour along with minimal SpO_2 < 92%;[14,15,20,28] and the diagnostic criterion for children with OSA in the 2020 guideline used an OAHI > 1 event/hour, which is consistent with the ICSD-3 guidelines.[16] In the 2020 guideline, like the ICSD-3 guidelines, OAHI reflects a sum of obstructive apneas plus hypopneas per hour during the sleep and emphasizes the importance of sleep apnea and hypopnea caused by obstructive factors in diagnosing pediatric OSA.[29] From the etiology of the definition of OSA, OAHI highlights

obstructive factors as the underlying issue leading to a series of pathophysiological changes in children with OSA, thus, using this parameter as the primary objective indicator for diagnosing OSA instead of using traditional AHI or OAI. The release and dissemination of the 2020 guideline will not only facilitate early identification of children with OSA who require intervention, but also align it with international guidelines, providing more objective and representative results for future research in the field of sleep.

In the present study, we aimed to objectively evaluate changes in cognitive function using more specific and detailed indicators, and therefore introduced the C-WYCSI and C-WISC subtests. Generally, IQ is considered stable in the absence of neurological injury or degenerative diseases. In the present study, we used FIQ, VIQ, and PIQ to measure individual abilities, as these IQ scores are widely applied in education, employment, and clinical practice.[30,31] Of these, VIQ is associated with a motor speech area,[32] reflecting verbal abilities such as abstract reasoning, attention, and short-term memory function in children.[22,23,30] PIQ is related to a motor hand area,[32] reflecting non-linguistic abilities such as perceptual reasoning, visual recognition, and motor coordination.[22,23,30] Although FIQ is not calculated based on subtest scores, it represents the combined level of VIQ and PIQ. Therefore, decreased FIQ, VIQ, and PIQ scores indicate impaired verbal and performance cognitive function. Additionally, the subtests associated with VIQ and PIQ reflect corresponding changes in cognitive function.

In recent years, several studies have consistently shown that patients with SDB have a higher risk of cognitive impairment than those without SDB.[33,34] Similarly, we found lower FIQ, VIQ and PIQ in children with OSA when compared with those without OSA based on the 2020 guideline. Notably, among the same cohort of participants, we observed that children diagnosed with OSA according to the 2020 guideline exhibited significant between-group difference in VIQ compared to the non-OSA group. However, no significant between-group difference in VIQ was observed between children diagnosed with OSA based on the 2007 guideline and those not diagnosed with OSA. In other words, there were significant intergroup differences in verbal function between children with OSA and those without OSA according to the 2020 guideline, but not according to the 2007 guideline. Consistent with our findings, a recent publication has also reported that the children with OSA showed lower FIQ and VIQ than those without OSA.[18] Additionally, Bourke et al reported that, compared with healthy controls, both children with OSA and those with primary snoring had lower FIQ and VIQ.[35] A previous literature review has reported that late diagnosis and treatment of OSA was associated with delayed acquisition of verbal skills in pediatric and adolescent patients.[36] Therefore, it is noteworthy that in management of children with OSA, equal importance should be given to assessing cognitive dysfunction and improving clinical symptoms. However, these previous studies did not assess the differences in verbal and performance subtests of C-WYCSI and C-WISC.

Currently, in the present study, we addressed this issue and have made some new findings. On the one hand, the subgroup analyses showed both the preschool and school-aged subgroups classified according to the 2020 guidelines exhibited more significant intergroup differences in verbal and performance subtests than those classified according to the 2007 guidelines in the corresponding subgroups. On the other hand, we found that both the preschool and school-aged subgroups had significant correlations between PSG parameters and cognitive tests scores in both the 2007 and 2020 guidelines, with more correlations in the latter than in the former. PSG parameters primarily measure clinical disease characteristics, including the sleep fragmentation and intermittent hypoxemia, and thus such abnormal correlations suggested that altered cognitive function may be caused by OSA. A study conducted in 2018 also supported our findings, indicating that two PSG indicators (ie, the accumulated time of oxygen saturation (SO_2) below 90% and its proportion of total sleep time) were negatively correlated with PIQ in preschool children with OSA.[17] Inconsistent with our findings, Bourke et al found no correlation between PSG parameters and neurobehavioral outcome measures (eg, FIQ, VIQ, and PIQ) in children with SDB, including those with OSA and primary snoring.[35] Therefore, the contradictory results of these studies may be due to the heterogeneity between the distinct study populations and the underrepresentation of neurobehavioral measures.

However, several factors limit our interpretation of the study results. First, the limited sample size in the present study may have weakened the statistical power and reliability; furthermore, this limitation prevented a detailed exploration of the disease severity of OSA. Future studies should be performed based on larger sample sizes to identify potential changes in cognitive function across disease severities of OSA. Second, we used the C-WYCSI and C-WISC to assess cognitive function in

children with OSA and those without OSA, which may have limited the number of cognitive domains covered. In the future, we should also employ more detailed neurobehavioral tests, and conduct additional research to more closely examine the impact of pediatric OSA on specific cognitive abilities. Lastly, the present study was cross-sectional and lacked follow-up data. Further longitudinal studies are needed to dynamically monitor changes in cognitive function and prognosis before- and after- treatment in children with OSA, further revealing the causal relationship between cognitive dysfunction and OSA.

Conclusion

In summary, the present study indicated that children with OSA had significant cognitive dysfunction according to the 2007 and 2020 guidelines. Meanwhile, the latter guideline has advantages in assessing the clinical characteristics of children with OSA, especially for verbal function. Therefore, we tend to recommend the promotion and application of the 2020 guideline in clinical practice for children with OSA. Further research is needed to explore the underlying mechanism linking cognitive dysfunction in children with OSA, and to identify the optimal treatments for each age subgroup to prevent the occurrence of cognitive dysfunction.

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The Medical Ethics Committee of Beijing Children's Hospital has approved the protocol for the present study and the guardians of all participants have signed the informed consent forms (ICFs), which was obtained in accordance with the relevant guidelines and regulations of the Declaration of Helsinki. We are very grateful to the patients and their guardians.

Author Contributions

All authors made a significant contribution to the work reported, whether that is in the conception, study design, execution, acquisition of data, analysis and interpretation, or in all these areas; took part in drafting, revising or critically reviewing the article; gave final approval of the version to be published; have agreed on the journal to which the article has been submitted; and agree to be accountable for all aspects of the work.

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Disclosure

The authors declared no conflicts of interest in this work.

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