Original Article

Assessment of upper airway obstruction in children with specific learning disorder

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Abstract

Aim: A growing number of findings suggest that there is an important relationship between upper airway obstruction (UAO) and specific learning disorder (SLD). However, existing evidence is limited to very few studies. We, thus, aimed to explore chronic UAO conditions in children with specific learning disabilities.

Materials and Methods: This study involved seventy-seven children aged 7 to 10 years with SLD and eighty-six healthy children matching in age and gender. Psychiatric disorders were diagnosed through the Diagnostic and Statistical Manual of Mental Disorders (DMS-5) Criteria. Porteus Maze Test and Kent-EGY test were used to assess the intelligence of the participants. The diagnoses of UAO were made by a physical examination, a detailed otorhinolaryngologic examination, the anamnesis and clinical history, anterior rhinoscopy, and flexible endoscopic nasopharyngoscopy according to the type of UAO.

Results: The rates of having at least one pathology causing UAO and secondary sleep difficulties due to UAO were significantly higher in children with SLD compared to controls. The severity of SLD was significantly associated with the severity of UAO and the presence of secondary sleep difficulties, but not the presence of UAO. The verbal and total IQ scores were significantly affected by the presence and severity of UAO, while the presence of secondary sleep difficulties significantly impacted all IQ scores.

Conclusion: Parents, teachers, otorhinolaryngologists, child psychiatrists, and pediatricians should be aware that the association between learning disorders and UAO. It also would be advisable to screen children with learning disorders in terms of UAO, and vice versa.

Keywords: Children; cognitive function; intelligence quotient; sleep disorders; specific learning disorder; upper airway obstruction

INTRODUCTION

Specific Learning Disorder (SLD) is defined as a persistent learning weakness in one or more domains that impacts a child's ability to the acquiring and using specific skills including attention, listen, speak, read, math, write, reason, and understand, without an intelligence problem (1). In general, SLD comprises a heterogeneous child population; while some children with SLD experience a prominent problem in a single specific skill, the majority of children with SLD have coexistence of learning disabilities in three major academic domains, namely reading, math, and writing. The three main types of SLD consist of SLD with impairment in reading (reading disorder, dyslexia), SLD with impairment in writing (the disorder of written expression, dysgraphia), and SLD with impairment in mathematics (mathematics disorder, dyscalculia). The definition refers to children without intellectual problems, uncorrected auditory or visual problems, other mental or neurological disorders, and adverse status (severe psychosocial deprivation, low-quality education, etc.), and

whose symptoms persisting for at least 6 months even with intervention. Signs and symptoms suggestive of SLD are an inability to master in reading, spelling, writing, and/or math skills which expected for age and grade levels, and difficulties in comprehending and following instructions and concepts, trouble in remembering (1,2). Although several potential causal factors (genetic and environmental factors) and theories have been proposed to explain the pathology of SLD, its exact pathophysiology remains unknown and SLD is considered a complex and multifactorial disorder (3).

Recently, a growing number of findings have indicated that there is a strong relationship between upper airway obstruction (UAO) and poorer neurocognitive function and reduced learning abilities. It has been emphasized that chronic nasal and nasopharyngeal obstructive conditions interfere with learning, and impact neurocognitive functioning, and so that they can play a role in learning disabilities. However, existing evidence is limited to very few studies, and the results

of some studies are inconsistent. Some researchers have stressed that children with UAO experience more difficulties in perception, sensorimotor integration and learning, lower performance in neurocognitive tests, and impaired academic functioning (4-11). Whereas others have suggested that the neurocognitive and academic functioning of these children are not affected, even with obstructive sleep apnea (OSA) which is an important complication of UAO (12-14). In this study, thus, we sought to explore chronic UAO conditions in children with specific learning disorders and to assess whether it is correlated with the severity of obstruction if there is a relationship between UAO and specific learning disorders. Thereby the current study aimed to fill the knowledge gap in this field and contribute to the literature. Second, it is our hope to raise the awareness of otorhinolaryngologists, child psychiatrists, and pediatricians regarding the relationship between UAO and learning difficulties.

MATERIALS and METHODS

Participants

Seventy-seven children aged 7 to 10 years with SLD [43 males (55.8%), 34 females (44.2%) mean age 8.06±0.87 years] and eighty-six healthy controls [49 males (57%), 37 females (43%) mean age 8.01±0.84 years, min-max:7-10 years] matched for age, gender, sociocultural characteristics and educational attainment to the SLD group participated in the study. Children with SLD admitted to the Child and Adolescent Psychiatry Clinic were consecutively enrolled in the study. Fourteen children were excluded before the examinations because eight of them did not meet the inclusion criteria, six of them refused to participate in the study. The control group was randomly recruited from healthy children who presented to the pediatrics clinic of the hospital, not suffering from UAO and who had normal school performance. Exclusion criteria included the presence of uncorrected auditory or visual problems, recurrent ear infections or fluid problems, chronic rhinosinusitis, an intercurrent upper respiratory tract infection within 4 weeks before recruitment, history of operation to eliminate the UAO, dental malocclusion, use of medication that could influence neurocognitive functions, other psychiatric disorders except for attention-deficit/hyperactivity disorder (ADHD), neurological disorders, known genetic or craniofacial anomalies, and any other underlying systemic diseases. Also, to increase the diagnostic validity, we chose patients with allergic rhinitis who have not any symptoms and un-medicated for at least 4 weeks, since drugs used in the treatment of allergic rhinitis could influence neurocognitive functions such as antihistaminics. We further excluded children with adverse conditions such as growth and development retardation, extreme poverty and severe psychosocial deprivation, and low-quality education and/or inadequate instruction in order to keep the effects of the confounding factors to a minimum.

Procedure

All children were administered the Porteus Maze Test (PMT) for performance intelligence quotient (IQ) and the Kent-EGY test for verbal performance IQ measurement. After IQ measurement, all children and their parents underwent a psychiatric examination which was based on the Diagnostic and Statistical Manual of Mental Disorders, Fifth Edition (DSM-5) (1), then, completed otorhinolaryngological consultation and examination. So, children potentially eligible for participation were determined by a child and adolescent psychiatrist and otorhinolaryngologists. Each child was submitted to a physical examination and a detailed otorhinolaryngologic examination in the otolaryngology clinic. The nasal pathologies and all UAOs from anterior nares to the posterior nasopharynx (such as septal deviation, nasal discharge, nasal polyposis, choanal atresia, adenoid hypertrophy, and palatine tonsil hypertrophy, etc.) were evaluated by a standard 2.8 mm-diameter flexible nasopharyngoscopy without using any premedication or anesthetic agent. Also, we investigated the size of the turbinates using anterior rhinoscopy, and we did not employ any other method for detecting UAO (lateral cephalography, etc.). Based on history and clinical examination, the presence of UAO symptoms for at least 3 months was considered chronic.

The size of adenoid tissue was categorized between I and IV grades according to the percentage of the adenoid tissue that occurs the blockage of the posterior choana in a sitting position and at rest: %0-25 (1), %25-50 (2), %50-75 (3), %75-100 (4) (15). The size of tonsil tissue was classified between I and IV grades according to the percentage of the tonsil tissue that occurs the obstruction of the oropharynx in a sitting position and at rest: %0-25 (1), %25-50 (2), %50-75 (3), %75-100 (4) (15). Severe hypertrophy for both was considered grade 3 and above, while grade 2 and below were allocated as mild hypertrophy. The diagnosis of allergic rhinitis was based on the presence of at least two of the symptoms of nasal congestion, rhinorrhea, sneezing, cough, post-nasal drip, constant desire to play with the nose, and itching for more than one hour in most days according to the anamnesis taken from the family and clinical history. We divided the allergic rhinitis into two groups as mild and moderate-severe according to the effect of symptoms on the quality of life (sleep, daily activities, sports, entertainment, school, etc.). None of the children in our study had other pathologies that could lead to upper airway obstruction such as choanal atresia, advanced (obstructive) nasal septum deviation, and polyposis.

This study was approved by the local Ethics Committee of the Medical Faculty of the Sivas Cumhuriyet University and conducted according to Good Clinical Practice procedures and the current revision of the Declaration of Helsinki. The aim and procedure of the study were explained to the children and parents or legal guardians verbally, written and verbal informed consent from parents and assent from children were obtained.

Assessments

Sociodemographic Data Form

Sociodemographic information and clinical data were obtained using a questionnaire specifically designed by the researchers. This questionnaire includes questions about age, gender, place of residence, family characteristics, child's clinical history, and health including the severity and the frequency of obstructive airway symptoms. In addition, body weight, height, and body-mass index (BMI: body mass/height²) of children were recorded using standard techniques. We also took the child's clinical history from the child's self and parents or guardians regarding secondary sleep difficulties due to obstructive respiratory events during the anamnesis. They answered questions regarding whether there is snoring, apnea, snorts and gasps, and mouth breathing. This questionnaire was evaluated by the researchers during otorhinolaryngologic and psychiatric examinations and the anamnesis.

Kent-EGY Test

The test, developed by Grace Kent is a brief individually administered verbal test and consists of 10 simple items. There is no time limit in the application. It is a test based on knowledge and language, not a speed test (16).

The Porteus Maze Test (PMT)

PMT is a nonverbal, performance intelligence test and assesses executive functions and behavioral disinhibition. It is based on the principle that the child can find the way out in the labyrinths and composed of 12 original maze designs with increasing difficulty (17). Turkish validity and reliability study was performed by Togrol (18).

Statistical analysis

Statistical data were analyzed using SPSS 23.0 (IBM SPSS, Version 22.0, IBM Corporation, Armonk, NY, USA). Normality was tested using the one-sample Kolmogorov-Smirnov test. The numerical and categorical data were presented as mean ± standard deviation (SD), number (n), median (min-max), and percentage (%) whenever appropriate. During statistical analyses, statistical comparisons were performed with the chi-square test, Mann-Whitney-U-Test, and Kruskal-Wallis-Tests. Significance was set at $p<0.05$.

RESULTS

Demographic and clinical characteristics of participants

In total, one hundred sixty-three children between the ages of 7 and 10 years participated in this study. There were no significant differences between groups for gender, age, family income, educational level, paternal education levels, place of residence, and Body Mass Index (BMI) (all p values>0.05). Based on DSM-5 (1), patients were categorized according to the severity of SLD as mild SLD (n=49, 63.6%) and moderate-severe SLD (n=28, 36.4%), and according to the types of SLD as dyslexia (n=19, 24.7%), dysgraphia (n=11, 14.3%), dyscalculia (n=8, 10.4%), and mixed-type (n=39, 50.6%). Forty-three patients (55.8%) presented also ADHD, 15 (34.9%) of whom were predominantly inattentive presentation (ADHD-PI), 7 (16.3%) of whom were predominantly hyperactive-impulsive presentation (ADHD-PH), and 21 (48.8%) of whom were combined presentation (ADHD-C). Demographic and clinical data of the sample are presented in Table 1.

Table 1. Sociodemographic characteristics of the sample			
	SLD group (N=77)	**Control group (N=86)**	**p-value***
Age (mean-years±SD)	8.06±0.87	8.01±0.84	0.723
Gender (n,%)			0.884
Male	43 (55.8)	49 (57)	
Female	34 (44.2)	37 (43)	
School class (n,%)			0.991
1st class	6 (20.8)	19 (22.1)	
2nd class	18 (23.4)	21 (24.4)	
3rd class	22 (28.6)	23 (26.7)	
4th class	21 (27.3)	23 (26.7)	
Place of residence (n,%)			0.870
Urban	51 (66.2)	58 (67.4)	
Rural	26 (33.8)	28 (32.6)	
Family income level (n,%)†			0.940
The minimum wage/less than minimum wage	30 (39)	34 (39.5)	
Above the minimum wage	47 (61)	52 (60.5)	
Education level of mother (n,%)			0.599
Primary education and lower	30 (39)	37 (43)	
Upper primary education	47 (61)	49 (57)	
Education level of father (n,%)			0.432
Primary education and lower	25 (32.5)	33 (38.4)	
Upper primary education	52 (67.5)	53 (61.6)	
Body Mass Index (mean±SD)	18.55±0.55	18.74±0.80	0.131

*The chi-square test for categorical variables and the Mann-Whitney U Test for continuous variables were used to test group differences.
Bold font indicates statistical significance: P < 0.05; †The level of income was determined by the minimum wage value on the date of the study.
SD, Standard Deviation; SLD, Specific Learning Disorder

Clinical features regarding upper airway obstruction

Clinical features regarding UAO and etiological causes leading to the obstruction are shown in Table 2. The detailed otorhinolaryngological examination showed that %27.3 (n=21) children in the SLD group had at least one pathology causing UAO and this rate was 7% (n=6) in the control group. The difference was statistically significant (p=0.001). The most common pathologies detected were adenoid hypertrophy, tonsillar hypertrophy, adenotonsillar hypertrophy, allergic rhinitis, and turbinate hypertrophy. Several children had more than one presenting pathology. None of the children in our study had other pathologies that could lead to an UAO such as obstructive nasal septum deviation (i.e., the deviation reached the lateral wall and compressed the inferior turbinate), choanal atresia, and polyposis. The percentages of adenoid hypertrophy (16.9% vs. 3.5%, respectively), tonsillar hypertrophy (13% vs. 3.5%, respectively) and allergic rhinitis (15.6% vs. 4.7%, respectively) were significantly higher in the SLD group compared to controls (all p values <0.05). Seven children (9.1%) in the SLD group and two children (2.3%) in the control group had turbinate hypertrophy, and six children (7.8%) in the SLD group and two children (2.3%) in the control group had adenotonsillar hypertrophy, but the differences were not statistically significant (p=0.086, p=0.150, respectively). As for the presence of secondary sleep difficulties due to UAO, the two groups differed significantly (p=0.011). Thirteen children (16.9%) in the SLD group and four children (4.7%) in the control group presented secondary sleep difficulties. However, the two groups did not differ in terms of the severity of the obstruction (mild vs. moderate-severe) (p=0.648) (Table 2).

Table 2. Clinical features of participants regarding upper airway obstruction			
	SLD group (N=77)	Control group (N=86)	p-value*
Upper airway obstruction (n,%)	21 (27.3)	6 (7)	**0.001***
Secondary sleep difficulties to upper airway obstruction (n,%)	13 (16.9)	4 (4.7)	**0.011***
Adenoid hypertrophy (n,%)	13 (16.9)	3 (3.5)	**0.004***
Tonsillar hypertrophy (n,%)	10 (13)	3 (3.5)	**0.025***
Adenotonsillar hypertrophy (n,%)	6 (7.8)	2 (2.3)	0.150**
Allergic rhinitis (n,%)	12 (15.6)	4 (4.7)	**0.019***
Turbinate hypertrophy	7 (9.1)	2 (2.3)	0.086**
Severity of the obstruction (n,%)			
Mild	10 (47.6)	4 (66.7)	0.648**
Moderate/severe	11 (52.4)	2 (33.3)	

*The chi-square test, **Fisher's Exact Test. Bold font indicates statistical significance: P < 0.05
SLD, Specific Learning Disorder

Table 3. The associations between severity of SLD and the presence and severity of upper airway obstruction			
	Severity of SLD		p-value*
	Mild	Moderate-Severe	
Upper airway obstruction			
Yes (n=21)	11 (22.4)	10 (35.7)	**0.209**
No (n=56)	38 (77.6)	18 (64.3)	
Severity of the obstruction			**0.030**, a**
Mild (n=10)	8 (72.7)	2 (20)	
Moderate-Severe (n=11)	3 (27.3)	8 (80)	
Secondary sleep difficulties			**0.001****
Yes (n=13)	3 (6.1)	10 (35.7)	
No (n=64)	46 (93.9)	18 (64.3)	

*The chi-square test, **Fisher's Exact Test. aIn statistical analysis, those without obstruction were excluded. Bold font indicates statistical significance: P < 0.05. Statistical analysis was performed by excluding the control group.
SLD, Specific Learning Disorder

No significant relationship was found between comorbid ADHD accompanying SLD and the presence and severity of UAO, and secondary sleep problems (all p values>0.05) (data not shown on the table). On the other hand, our sample size did not allow us to statistical compare the relationship between SLD type and the presence of secondary sleep difficulties and UAO. Thus, we handled the broader category of SLD in the statistical analysis instead of focusing on specific categories of diagnosis.

Also, the analysis of our results revealed that no significant relationship between the presence of UAO and the severity of SLD (p=0.209), but a significant and positive association between the severity of UAO and the severity of SLD (p=0.030). In other words, the vast majority of children with moderate-severe SLD (%80) had also moderate-severe obstruction. Again, the presence of secondary sleep difficulties was also significantly and positively associated with SLD severity. The rate of children with secondary sleep problems in moderate-severe SLD was significantly higher than those in mild SLD (35.7% vs. 6.1%, respectively, p=0.001). The associations between severity of SLD and the presence and severity of UAO are summarized in Table 3.

Intelligence quotient (IQ) measurement results
Intelligence tests indicated that the mean scores of verbal IQ (88.32±8.06 vs. 100.73±7.42, respectively, p<0.001) and the mean scores of total IQ (97.39±4.96 vs. 102.26±7.35, respectively, p<0.001) were significantly lower among children with SLD than controls. On the contrary, the mean scores of performance IQ (101.49±9.49 vs. 104.77±8.15, respectively, p=0.080) were similar between the two groups. Examining the relationship between the presence of UAO and IQ scores, we found that verbal IQ and total IQ scores were significantly negatively affected by the presence of UAO (both p<0.001), but the performance IQ was not affected (p=0.122). The IQ measurement results are displayed in Table 4.

Table 4. Comparisons of the mean IQ scores according to the absence or presence of upper airway obstruction and the groups						
	Groups			**Presence of Upper Airway Obstruction**		
	SLD group (N=77)	**Control group (N=86)**	**p-value***	**Yes (n=27)**	**No (n=136)**	**p-value***
Verbal IQ (mean±SD)	88.32±8.06	100.73±7.42	**<0.001**	85.67±5.62	96.70±9.55	**<0.001**
Performance IQ (mean±SD)	101.49±9.49	104.77±8.15	0.080	101.33±6.89	103.60±9.26	0.122
Total IQ (mean±SD)	97.39±4.96	102.26±7.35	**<0.001**	94.85±4.84	100.97±6.62	**<0.001**
*The Mann-Whitney U Test was used to test group differences. Bold font indicates statistical significance: P < 0.05 IQ, intelligence quotient; SD, Standard Deviation; SLD, Specific Learning Disorder						

Table 5. The associations between IQ scores and the severity of upper airway obstruction and the presence of secondary sleep difficulties							
	Severity of Upper Airway Obstruction			**p-value***	**Secondary Sleep Difficulties**		**p-value****
	Mild (n=14)	**Moderate-Severe (n=13)**	**None (n=136)**		**Yes (n=17)**	**No (n=146)**	
Verbal IQ (mean±SD)	86.64±5.94	84.62±5.28	96.70±9.55	**<0.001**	84.71±5.42	96.05±9.63	**<0.001**
Performance IQ (mean±SD)	101.64±9.04	101±3.76	103.60±9.26	0.256	98.94±6.66	103.72±9.05	**0.014**
Total IQ (mean±SD)	96.29±5.01	93.31±4.32	100.97±6.65	**<0.001**	92.35±2.82	100.84±6.54	**<0.001**
*The Kruskal Wallis Test, **The Mann-Whitney U Test Bold font indicates statistical significance: P < 0.05 IQ, intelligence quotient; SD, Standard Deviation							

Regarding the severity of UAO, similar to the presence of UAO, we detected that verbal IQ and total IQ scores were significantly influenced by the severity of UAO. Accordingly, children with moderate-severe obstruction had the lowest verbal and total IQ average scores, but the scores did not differ significantly from those with mild obstruction, and regardless of severity, the verbal and total IQ mean scores of all children with UAO were significantly lower than the control group (both p<0.001). Whereas, the mean scores of performance IQ were similar among the three groups (p=0.256). On the other hand, the presence of secondary sleep difficulties significantly adversely impacted all IQ scores (all p-values <0.05). The mean IQ scores according to the severity of UAO and secondary sleep difficulties are given in Table 5.

DISCUSSION

In this study, we investigated the chronic UAO conditions among children with SLD and their healthy peers as well as the correlation between learning disabilities with the severity of obstruction, and found noteworthy significant differences across the groups. Virtually, limited research, to our knowledge, has specifically focused on the association between learning disabilities and UAO (6,9-11). Therefore the deleterious effects of UAO on neurocognitive and academic functioning are less clear. Furthermore, the majority of existing studies have been conducted on children with sleep-disordered breathing which is a complication related to UAO (8,12,13,19). Thus, the present study is one of the few studies investigating the relationship between UAO and specific learning disorders.

Taken together, available findings suggest that children with chronic UAO exhibit more neurocognitive deficits including attention deficits, impairments in memory and learning abilities than their healthy peers (5-7,9-11). In addition, previous studies have repeatedly demonstrated that children with chronic UAO, in particular, if the sleep-disordered breathing is added, have diminished daytime functioning in neurocognitive and academic domains, hence poorer school performance and lower grade point average (4-8,20). Moreover, it has been demonstrated that treatments for nasal and nasopharyngeal obstruction such as tonsillectomy and adenotonsillectomy prevent subsequent neurocognitive deficits, and can significantly alleviate diminished neurocognitive and learning skills (8,23,32). Nevertheless, studies have indicated that the reversibility of impaired neurocognitive functions is partial (32). However, little is known about the mechanism of the relationship between UAO and poorer neurocognitive function and reduced learning abilities, and the pathophysiological mechanism and causal pathways regarding how UAO interferes with learning are not fully understood. Although relatively scarce documentation, the most overemphasized mechanisms are intermittent hypoxemia and hypercarbia episodes of the brain, and cellular and neurochemical changes secondary to decreased arterial blood oxygen saturation and blood-gas abnormalities caused by impaired nasal airflow (20-24). In this context, it has been suggested that blood oxygen desaturation and intermittent hypoxia of the brain may cause a homeostatic imbalance in neuronal and glial cells within the certain cortical areas, primarily in the prefrontal cortex, by triggering changes in cellular and neurochemical. The researchers have argued that these pathological processes impair the functions of the prefrontal cortex, which is responsible for neurocognitive functions, which, in turn, lead to impaired cognitive and learning skills (7,21-24). As a second possible or additional underlying mechanism, it has been proposed secondary recurrent ear infections or fluid problems and infections of the upper respiratory tract, which can influence attention, learning, and other neurocognitive abilities (25). Finally, another and important well-known mechanism is severe sleep difficulties called childhood sleep-disordered breathing (SDB) including from simple snoring and mouth breathing to advanced OSA at night (4,26,27). The authors have demonstrated that UAO impact neurocognitive functioning through the disruptive effect on quantity and quality of sleep which are quite crucial for neurocognitive development and enhancing memory and learning. Because, it is known widely that long-term interruptions of sleep, frequent sleep fragmentation and awakening episodes, low efficiency of sleep, or other sleep disturbances adversely affect cognitive performance (8,28). Earlier studies have also shown that sleep-related breathing disorders caused by UAO can lead to daytime somnolence and sleepiness, fatigue, deficits in attention vigilance, and poor concentration, which may be associated with neurocognitive and academic functioning impairments (4,26,27). In parallel with this,

the researchers reported that children with snoring and OSA have poor general intelligence, language, and visual-spatial skills, low performance in mathematics, science, and spelling, and impaired immediate memory, learning indices, and attention. Moreover, neuropsychological deficits are found in correlation with the severity of apnea and polysomnographic findings (29-31).

In fact, the small number of studies have tested the association between learning disabilities and chronic UAO, and these studies have reported that the academic poor achievers and children with learning disabilities have greater rates of UAO and sleep-disordered breathing as high as 40-54% (9,10,32). A study on mouth breathing in children with learning disorders have detected UAO in 54.2% of children with learning disabilities (9). Another study, screening sleep-disordered breathing among students with low academic performance, has reported that these children have 40% sleep-disordered breathing and show a significant improvement in one year after adenotonsillectomy, but there is no change in untreated children (32). We found adenoid hypertrophy, tonsillar hypertrophy, adenotonsillar hypertrophy, allergic rhinitis, and turbinate hypertrophy as the predominant causes of UAO among children with SLD, with several children had more than one presenting pathology. Our results are consistent with other reports (9,33). Children with SLD in our sample had a significantly higher prevalence of adenoid hypertrophy, tonsillar hypertrophy, and allergic rhinitis compared to controls. However, instead of focusing on individual diagnostic categories, we addressed the broader UAO category. Our results indicated that 27.3% of children with learning disabilities have chronic UAO and 16.9% of these children manifest symptoms of sleep disturbances, and these rates are significantly higher than the control group, which corroborates findings in the literature (9,32).

On the other hand, relatively more studies have examined neurocognitive disorders and learning disabilities in children with UAO and sleep-disordered breathing. The common result of these studies indicating an association between learning difficulties and UAO is that UAO can lead to several negative effects on overall cognitive performance and intellectual capacity, learning, attention, memory, language, and academic performance. These studies have reported substantial neurocognitive impairments including deficits in attention and vigilance, weaker sensorimotor integration, visual sequencing, and perception, diminished mental flexibility, impaired memory and learning skills, poor performance on cognitive and academic tests (math, science, reading, speaking, writing, and spelling), and hence poorer neurocognitive and academic functioning in children with UAO (4-6,10,23,29,30,34). The pattern of results suggests that the impact of UAO and sleep-disordered breathing on general cognitive functioning is mostly in the realm of the verbal rather than on the visuospatial domain. In this context, the authors have speculated that intermittent hypoxemia and hypercarbia episodes can lead to reduced blood flow

to the frontal-parietal-temporal neural network, which is strongly associated with the verbal working memory, hence, the verbal domain and functioning are more affected (35-37). A study by Kuroishi et al. has indicated that children with mouth-breathing syndrome show more difficulties in dealing with syntactical complexity and comprehension written language, and unsatisfactory arithmetic skills indicating difficulties with numerical operations than their healthy peers (11). Another study investigating working memory impairment in children with sleep-related breathing disorders have also reported considerable impairment of the working memory in the verbal domain, in particular, verbal storage, and retention of information in these children compared to controls (5). The same study has proposed that impairments in verbal working memory which is associated with language learning should be regarded as specific (5). On the other hand, it is known that verbal working memory is a major predictor of word reading and text comprehension and the potential far-reaching impact of working memory deficits in language acquisition (38). Also, verbal working memory is implicated in acquire other abilities such as mathematic skills (39). Thus, learning disorders of children with UAO and sleep-disordered breathing could be explained by working memory deficits that may impact the trajectory of learning potentials. Our results about a differential impact of UAO on verbal IQ versus performance IQ echoed the pattern identified in these studies, in which sleep-disordered breathing is related to impaired verbal memory but not visual memory. In accordance with existing knowledge, our study revealed that the presence of an obstruction in the upper respiratory tract is negatively related to verbal and total IQ levels, while secondary sleep difficulties affect all three IQ levels negatively, suggesting secondary sleep difficulties more a severe condition. Moreover, we found that the severity of UAO is strongly associated with lower values of verbal and total IQ. Additionally, in our study, the severity of UAO and the presence of secondary sleep difficulties were also related to the severity of SLD, but not the presence of UAO. Our findings are consistent with previous studies showing that the positive association between verbal IQ and the severity of the obstruction, suggesting the positive correlation between learning abilities and the severity of the obstruction (5,9,34). Most of the studies published so far have shown that children with UAO experience more difficulties in perception and sensorimotor integration and learning, and that the decrease in verbal ability is correlated with the severity of the obstruction and sleep disturbances (OSA), similar to our results (4,5,7,8), although some studies have failed to find a relationship between learning disabilities and obstructive respiratory events (12,14). However, these studies have produced conflicting results on the relationship between learning abilities and the severity of the obstruction (9, 40). These contradictory findings may be attributed to heterogeneity in study settings, small sample sizes, and methodological issues, in particular, the use of report-based (e.g., questionnaire) versus performance-based (e.g., neurocognitive tests)

measures to assess learning skills as well as the source of cases, included age ranges, variation in diagnostic criteria. Nevertheless, it should be noted that the paucity of studies reporting on the UAO in children with learning disabilities, and that the findings are limited to very few studies in the literature. Therefore, it would not be easy to make meaningful comparisons between studies.

Our study has several limitations. First, we focused only on verbal and performance subsets of intelligence, and total IQ, since the most comprehensive intelligence test was taking too long, we could not apply it in outpatient conditions. Second, we did not repeat the IQ measurements after treatment for UAO, however, at least one-year follow-up may be the subject of another study. Third, polysomnography could not be included in our measurements, since it is a costly and difficult measurement for children. Finally, the design of the study was cross-sectional. These weaknesses prevent the generalization of our results and the determination of definitive causality. Despite these limitations, to our knowledge, our study is one of the limited numbers of studies investigating the relationship between UAO and specific learning disorders. As a result, our findings provide considerable information about the importance of IQ measurements in children with UAO. Bearing these limitations in mind, the results of this study should be interpreted carefully and need to be confirmed by further studies that control our weak aspects. Importantly, it would be advisable for future studies to examine whether there are alterations of IQ valuables and an increase in learning and school performance after clinical and/or surgical interventions for UAO. We look forward to at least one-year follow-up studies on the improvement of learning disorders by clinical and/or surgical interventions for UAO, in this field.

CONCLUSION

To summarize, we found data that the higher prevalence of UAO in children with learning disorders, and the set of results obtained here suggests that UAO in childhood can impair intellectual abilities, cognitive systems, and learning processes. Our results show that the severity of UAO and the presence of secondary sleep difficulties are strongly associated with lower IQ values and more severe SLD. It is conceivable that learning disorders may be a symptom or a consequence of UAO. Parents, teachers, otorhinolaryngologists, child psychiatrists, and pediatricians should be aware that the association between learning disorders and UAO. It also would be advisable to screen children with learning disorders in terms of UAO, and vice versa. Children, their parents, and teachers should be informed of the neurocognitive and academic outcomes of pediatric UAO, and interventions aimed at eliminating the obstruction should be proposed in order to potentially prevent or attenuate long-term damage to the developing brain of the UAO.

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