

Neurobehavioral Assessment in Children With Mouth-Breathing Syndrome: A Cross-Sectional Observational Study Using P300 and Standardized Behavioral Scales

Máira Soares Torres

torres.mairasoares@gmail.com

Universidade Federal de Minas Gerais (UFMG)

Ludimila Labanca

Universidade Federal de Minas Gerais (UFMG)

Letícia Paiva Franco

Universidade Federal de Minas Gerais (UFMG)

Iúri Soares Torres

Hospital de Base do Distrito Federal

Helena Maria Gonçalves Becker

Universidade Federal de Minas Gerais (UFMG)

Research Article

Keywords: Mouth-Breathing Syndrome, Child Behavior Disorders, Neurobehavioral Manifestations

Posted Date: September 23rd, 2026

DOI: <https://doi.org/10.21203/rs.3.rs-10951786/v1>

License: © ⓘ This work is licensed under a Creative Commons Attribution 4.0 International License. [Read Full License](#)

Additional Declarations: No competing interests reported.

Abstract

Objectives

Allergic rhinitis (AR) and adenotonsillar hypertrophy (ATH) are very prevalent conditions in the pediatric population and a significant number of children exhibit signs of cognitive and behavioral impairment. The magnitude of this dysfunction is still unclear. The purpose of this study is to objectively evaluate neurobehavioral dysfunction in children diagnosed with Mouth-breathing Syndrome (MBS) and investigate associations between behavioral scales and cognitive aspects with AR/ATH by applying the Strengths and Difficulties Questionnaire (SDQ), the Swanson, Nolan, and Pelham Scale version IV (SNAP-IV), and the Cognitive Auditory Evoked Potential (P300).

Methods

44 children aged 6–14 years were equally distributed into 4 groups: control and mouth breathers (AR, ATH and ATH + AR). All children underwent immediate hypersensitivity skin test, nasopharyngolaryngoscopy, audiometry and impedance testing, active anterior rhinomanometry, SDQ, SNAP-IV and P300.

Results

Children with MBS presented higher scores on the emotional problems ($p = 0.001$), conduct ($p = 0.029$) and hyperactivity ($p = 0.001$) scales and worse scores on the prosocial scale ($p = 0.015$) of the SDQ, and more symptoms of inattention ($p = 0.003$) and impulsivity ($p = 0.000$) on the SNAP-IV. Latency of the P300 was higher in mouth breathing children ($p = 0.017$).

Conclusion

Children with MBS showed increased nasal resistance, greater emotional and behavioral dysregulation, lower social skills, and lower performance in a test that evaluated attention and working memory. Notably, the specific etiology of MBS (AR, ATH, or ATH + AR) did not significantly alter these findings among the mouth-breathing groups.

1. Introduction

Mouth-Breathing syndrome (MBS) affects up to 50% of school-aged children¹ and is defined as prolonged oral breathing for over six months², with diverse etiologies such as allergic rhinitis (AR) and adenotonsillar hypertrophy (ATH)³. AR results from exposure to inhaled allergens, triggering an immunoglobulin E-mediated inflammatory response^{4,5}. ATH affects up to 34% of school-aged children⁶, causing upper airway obstruction (UAO). MBS is linked to cognitive dysfunction and poorer academic performance in comparison to nasal breathers^{7,8,9}. The majority of existing studies rely on parent-reported outcomes and academic performance to evaluate cognitive and behavioral impairments, lacking objective assessments—especially regarding cognitive domains. Within this scope, the long latency auditory evoked potential P300 may serve as an objective biomarker for this dysfunction.

This study addresses a gap in research by objectively assessing cognitive and behavioral aspects of mouth-breathing children, categorized by etiology^{10,11}, using the Strengths and Difficulties Questionnaire (SDQ), the parent form of the Swanson, Nolan, and Pelham-Version IV Scale (SNAP-IV), and the long latency auditory evoked potential P300.

2. Materials and Methods

2.1 Study participants

All participants provided informed consent before engaging in the study, which adhered to the principles outlined in the Declaration of Helsinki. Approval for the protocol was granted by the Ethics Committee of Universidade Federal de Minas Gerais (No. 57202722.5.0000.5149) on May 17, 2022. Clinical trial number: not applicable. The sample comprised children aged six to 14 years, encompassing both mouth and nasal breathers, seen at the outpatient clinics of the Otorhinolaryngology Department of Hospital das Clínicas da Universidade Federal de Minas Gerais (ORL HC-UFMG). Prior to participation, informed consent was obtained from all participants and their legal guardians following a thorough explanation of the study protocols.

Inclusion criteria for children with MBS comprised those aged six to 14 years, previously diagnosed with ATH and/or AR, having undergone nasofibrolaryngoscopy and allergy skin prick tests. Additionally, inclusion required a palatine tonsil classified as Brodsky's grade III or IV and/or adenoids obstructing over 60% of the nasopharynx and/or a clinical history of nasal symptoms exacerbated by contact with respiratory allergens and positive skin prick tests for aeroallergens. Normal tonal audiometry, logaudiometry, and immittance were prerequisites, along with the ability to perform anterior active rhinomanometry and P300. Control group inclusion criteria mirrored those of the AR and ATH groups, except for the determination of nasal breathers after thorough evaluation. These procedures were necessary to objectively exclude upper airway obstruction and allergic disease in the control group.

Exclusion criteria for all groups included prior adenotonsillectomy, recent respiratory infections, dermatological lesions hindering skin prick tests, recent use of medications that would interfere with nasal airflow, and children with syndromic features, craniofacial deformities, prior diagnoses of cognitive or behavioral dysfunction, nasal septal perforation, or complete nostril obstruction^{12,13}.

Sample size calculation was performed for a comparative study based on the expected prevalence of cognitive and behavioral disturbances. Drawing from previous literature, the prevalence was estimated at 78%¹⁴, 75%¹⁵, and 80%¹¹ for children with allergic rhinitis (AR), adenotonsillar hypertrophy (ATH), and concurrent ATH and AR (ATH + AR), respectively, compared to 7.8%¹⁶ in nasal-breathing controls. To detect significant differences with a statistical power of 80% and a significance level of $\alpha = 0.01$, a minimum sample size of 11 participants per group was required, resulting in a total study population of 44 children.

2.2 Mouth Breathing Assessment

Subjects underwent comprehensive evaluations by otorhinolaryngologists to assess nasal obstruction, hyperreactivity, and rhinitis-related symptoms. This included thorough history-taking, physical examinations, and rhinoscopy. All participants underwent nasopharyngolaryngoscopy, skin prick tests with prevalent respiratory allergens in the Brazilian pediatric population, and Active Anterior Rhinomanometry (AAR). Pharyngeal tonsil hypertrophy was assessed through endoscopic examination using a flexible nasopharyngoscope¹⁷. Palatine tonsil staging followed the Brodsky classification¹⁸. Immediate hypersensitivity skin tests were quantitatively interpreted, considering papules at least 3 mm larger than the negative control as positive^{13,19}. AAR measured inspiratory nasal flow and nasal resistance values, while environmental conditions were controlled. Nasal flows (INF_R , INF_L) and total nasal inspiratory flow (INF_T) were determined¹². Inspiratory nasal flow values were adjusted based on height as proposed by Zapletal et al. (2002).

2.3 Behavioral Assessment

To diagnose cognitive and behavioral dysfunction in children, various tools, including neuropsychological tests, questionnaires, and electrophysiological examinations, are employed. The Strengths and Difficulties Questionnaire (SDQ) is an objective assessment tool completed by caregivers, exploring emotional symptoms, conduct problems, hyperactivity, inattention, peer relationships, and prosocial behavior²⁰. The Swanson, Nolan, and Pelham Scale version IV (SNAP-IV) evaluates core symptoms of attention deficit hyperactivity disorder (ADHD), with caregivers assigning severity levels to inattention and hyperactivity/impulsivity symptoms²¹.

2.4 Objective Cognitive Assessment

The long-latency auditory evoked potential (P300) serves as an objective marker for central auditory processing, showing strong correlations with neuropsychological evaluations in assessing cognitive skills, including selective attention, memory, reaction time, and conceptual processing²². Testing was conducted in a sound-attenuated room utilizing a CONTRONIC® MASBE device, with electrode placement adhering to the International 10–20 System. Auditory stimulation followed an oddball paradigm (80% frequent at 1,000 Hz; 20% rare at 2,000 Hz) delivered at 80 dB HL after subject familiarization. Abnormal responses were characterized by the absence of the P300 component or prolonged wave latency based on Fuchigami et al.'s parameters²³. Prior to electrophysiological testing, pure-tone audiometry, speech audiometry, and tympanometry were performed to exclude peripheral auditory pathology, establishing normal hearing as a mandatory inclusion criterion.

2.5 General study design

This observational, cross-sectional study was conducted at a single tertiary hospital in Brazil from February to December 2022, focusing on assessing cognitive and behavioral aspects in children with Allergic Rhinitis and/or Adenotonsillar Hypertrophy compared to nasal breathers of the same age. A total of 44 children, meeting specific inclusion and exclusion criteria, were distributed across four groups as follows: Group 1 (Control), Group 2 (AR), Group 3 (ATH), and Group 4 (ATH + AR), with 11 children in each group. The comprehensive evaluation included medical history, physical examination, audiometry, tympanometry, nasofibropharyngoscopy, skin prick tests, the application of the SDQ and SNAP-IV, Active Anterior Rhinomanometry (AAR), and P300. Socioeconomic status, symptom severity, and parents' education were considered. Socioeconomic status followed the Brazilian Institute of Geography and Statistics (IBGE) classification, based on family income. Symptom severity was subjectively assessed using the Visual Analog Scale (VAS), with caregivers rating intensity on a scale from zero to 10.

Nine children were excluded due to the following reasons: three for presenting syndromic features, four for not being able to complete the AAR and/or the P300, one for presenting altered hearing acuity, and one for withdrawal of consent after the beginning of the research protocol.

2.6 Statistical Analysis

Categorical data were expressed as percentages and absolute values, with group comparisons using the chi-square test. Due to non-normality identified by the Shapiro Wilk test, continuous variables were presented as medians and quartiles. Group comparisons for continuous variables utilized the Kruskal Wallis test with Bonferroni post-test, and Mann Whitney test for two-group comparisons. Spearman's correlation analyzed quantitative variables. All analyses were conducted using International Business Machines - Statistical Package for Social Sciences (IBM - SPSS) version 25, and significance was set at 5%.

3. Results

3.1 Demographic and clinical data

Table 1 displays the demographic data for the four groups, revealing no significant differences in age, sex, economic background, or parents' education. All participants attended public schools. The subjective assessment of symptom severity, measured by the visual analog scale (VAS), showed significantly lower scores in nasal breathers. However, among mouth breathers, there was no statistically significant difference based on etiology.

Table 1
Demographic data

Variable	Group 1 Control	Group 2 AR	Group 3 ATH	Group 4 ATH + AR	p-value
Age (years) †	9 (6–12)	8 (7–10)	7 (6–8)	8 (6–9)	0.257
Educational level (years) †	3 (0–5)	3 (2–4)	1 (0–2)	2 (0–3)	0.168
Mother's educational level (years)†	8 (7–11)	11 (11–11)	8 (8–13)	11 (11–11)	0.193
Father's educational level (years) †	10 (7–11)	10 (7–11)	8 (7–11)	8 (8–11)	0.532
Female ‡	7 (63.6)	3 (27.3)	8 (72.7)	3 (27.3)	0.056
Male ‡	4 (36.4)	8 (72.7)	3 (27.3)	8 (72.7)	0.056
Economic class "C" ‡	4 (36.4)	8 (72.7)	7 (63.6)	8 (72.7)	0.249
Economic class "D" ‡	7 (63.6)	3 (27.3)	4 (36.4)	3 (27.3)	0.249
Symptoms severity – VAS †*	0 (0)	6 (5–7)	7 (5–7)	6 (5–7)	0
Adenoids size †**	20 (5–20)	20 (10–30)	70 (30–80)	80 (60–80)	0.0001
Palatine tonsils size ‡*** I	8 (72.7)	8 (72.7)	1 (9.0)	1 (9.0)	0.0001
Palatine tonsils size ‡*** II	3 (27.3)	3 (27.3)	2 (18.0)	0 (0.0)	0.0001
Palatine tonsils size ‡*** III	0 (0.0)	0 (0.0)	7 (64.0)	10 (91.0)	0.0001
Palatine tonsils size ‡*** IV	0 (0.0)	0 (0.0)	1 (9.0)	0 (0.0)	0.0001

†Values expressed as median (Q1-Q3). Comparison was performed using Kruskal-Wallis test;

‡ Values in N (%). Comparison was performed using the chi-square test;

*Control group has lower score and other groups are statistically similar;

**Control and AR groups have significantly different results from ATH and ATH + AR groups;

***In control and AR groups, grades I and II are predominant, while grades III and IV are predominant in ATH and ATH + AR groups;

Size of palatine tonsils - I: < 25%, II: ≥ 25% and < 50%, III: ≥ 50% and < 75%, IV: ≥ 75% (Brodsky Classification)

3.2 Analysis of long-latency auditory potential P300

Comparison of P300 latency and amplitude between mouth breathers and healthy controls revealed significantly increased latencies in the mouth-breathing group across both ears (right ear: $p = 0.008$; left ear: $p = 0.017$). In contrast, amplitude measurements showed no significant intergroup variations. Further pairwise analysis indicated that control participants maintained significantly shorter latencies than all other evaluated groups, whereas latencies among the remaining groups did not differ significantly.

3.3 Comparison between the scores obtained on SDQ and SNAP-IV questionnaires

Analysis of behavioral questionnaires revealed that mouth-breathing children (Groups 2, 3, and 4) scored significantly higher than control participants on the SDQ emotional ($p = 0.001$), conduct ($p = 0.029$), and hyperactivity ($p = 0.001$) subscales, as well as the SNAP-IV Inattention ($p = 0.003$) and Hyperactivity/Impulsivity ($p < 0.001$) domains. In contrast, control subjects achieved significantly higher prosocial behavior scores on the SDQ ($p = 0.015$; Table 2).

Intergroup comparison across all four cohorts indicated that Group 2 presented significantly higher scores in SDQ hyperactivity and SNAP-IV inattention and hyperactivity compared to Group 1, whereas Groups 3 and 4 showed comparable results. Furthermore, Group 1 scored significantly lower on the emotional subscale than the clinical groups ($p = 0.009$), among which no significant differences were found (Table 3).

Table 2
Comparison of scores between nasal and mouth breathers

Variable	Group 1	Group 2 + Group 3 + Group 4	p-value
	Median (Q1-Q3)		
SDQ Score - Emotional	2 (1–3)	5 (4–7)	0.001
SDQ Score - Conduct	1 (0–2)	2 (1–4)	0.029
SDQ Score - Hyperactivity	3 (1–4)	6 (4–7)	0.001
SDQ Score – Peer problems	2 (1–3)	2 (1–3)	0.999
SDQ Score – Prosocial behavior	10 (9–10)	9 (8–9,5)	0.015
SDQ Score – Family impact	0 (0–0)	0 (0–0)	0.538
SNAP Score - Inattention	4 (3–6)	8 (5,5–14)	0.003
SNAP Score - Hyperactivity and Impulsivity	2 (1–3)	7 (4–15)	0
Comparison performed using Mann Whitney test. Data expressed as median (Q1-Q3). Group 1: Control; Group 2: Allergic Rhinitis (AR); Group 3: Adenotonsillar Hypertrophy (ATH); Group 4: AR + ATH; SDQ: Strengths and Difficulties Questionnaire; SNAP: Pelham Scale version IV			

Table 3
Comparison of scores between control and mouth-breathing children by etiology

Variable	Group 1 Control	Group 2 AR	Group 3 ATH	Group 4 ATH + AR	p-value
	Median (Q1-Q3)				
SDQ score - Emotional*	2 (1–3)	5 (4–7)	6 (3–8)	5 (4–7)	0.009
SDQ score - Conduct	1 (0–2)	2 (1–5)	3 (1–4)	2 (0–4)	0.075
SDQ score - Hyperactivity **	3 (1–4)	7 (5–8)	5 (4–6)	7 (4–7)	0.004
SDQ score - Peer problems	2 (1–3)	2 (2–4)	2 (1–2)	2 (1–3)	0.409
SDQ score - Prosocial behavior	10 (9–10)	8 (7–10)	9 (8–10)	9 (7–9)	0.077
SDQ score – Family impact	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–1)	0.768
SNAP score - Inattention **	4 (3–6)	11 (5–15)	8 (7–14)	8 (5–14)	0.036
SNAP score - Hyperactivity and Impulsivity **	2 (0–5)	8 (4–15)	5 (2–17)	9 (6–15)	0.004

Comparison performed using the Kruskal Wallis test. Data presented as median (Q1-Q3); * Group 1 shows the lowest result, other groups are statistically equal; **Statistically significant difference only between group 1 and group 2. AR: Allergic Rhinitis; ATH: Adenotonsillar Hypertrophy; SDQ: Strengths and Difficulties Questionnaire; SNAP: Pelham Scale version IV.

3.4 Correlation between P300 and scores on behavioral assessment questionnaires

Correlation testing revealed statistically significant positive associations between bilateral P300 wave latencies and the SDQ hyperactivity and conduct subscales (Table 4), while all other SDQ correlations were non-significant. Regarding the SNAP-IV questionnaire, P300 latency across both ears correlated positively with both inattention and hyperactivity-impulsivity subscales (Table 4). This pattern demonstrates that increased P300 latency corresponds to higher symptom scores, highlighting a link between neurophysiological deficits in attention and working memory and heightened behavioral or hyperactive impairments.

Table 4
Correlation between P300, SDQ and SNAP scores (n = 44)

		SDQ Emotional	SDQ Conduct*	SDQ Hyperactivity **	SDQ Peer Problems	SDQ Prosocial Behavior	SDQ Family impact	SNAP – Inattention**	SNAP - Hyperactivity and Impulsivity*
Latency P300 Right Ear	Correlation coefficient	0.112	0.458	0.558	-0.048	-0.186	0.154	0.556	0.3
	p-value	0.469	0.002	0	0.757	0.227	0.318	0	0.048
Latency P300 Left Ear	Correlation coefficient	0.085	0.404	0.589	-0.081	-0.17	0.189	0.523	0.333
	p-value	0.583	0.007	0	0.601	0.27	0.219	0	0.027

Correlation performed by Spearman's correlation. Data shown in scores obtained in each category of the questionnaires, P300 latency expressed in milliseconds, P300 amplitude expressed in microvolts. SDQ: Strengths and Difficulties Questionnaire; SNAP: Pelham Scale version IV. *Significant correlation at the 5% level. **Significant correlation at 1% level.

3.5 Correlation between measured nasal airflow resistance and performance on SDQ and SNAP-IV questionnaires and on P300

Correlation analysis demonstrated a significant negative association between total inspiratory nasal flow and SDQ conduct subscale scores ($p = 0.003$), indicating that higher nasal patency is associated with fewer behavioral conduct problems across settings compared to children with mouth breathing. No statistically significant correlations were found for any other variables ($p > 0.05$).

3.6 Secondary correlations

No significant differences or correlations were observed when evaluating SDQ, SNAP-IV, and P300 outcomes across economic classes or parental education levels ($p > 0.05$). Conversely, symptom severity reported via the Visual Analog Scale (VAS) was significantly and positively associated with higher scores on the SDQ emotional, conduct, hyperactivity, and family impact subscales (Table 5). Higher VAS scores were also positively correlated with prolonged bilateral P300 latencies and increased SNAP-IV inattention and hyperactivity-impulsivity scores. Taken together, these data indicate that parental perception of disease severity serves as a reliable indicator of child cognitive and behavioral dysfunction, exceeding the predictive value of demographic variables.

Table 5
Symptoms severity (VAS) and performance on questionnaires and P300

Correlation coefficient	SDQ - Emotional**	SDQ - Conduct**	SDQ Hyperactivity *	SDQ - Peer problems	SDQ - Prosocial behavior	SDQ – Family impact*	Latency P300 RE**	Amplitude P300 RE	Latency P300 LE*	Amplitude P300 LE	SNAP Inattent **
	0,398	0,414	0,309	-0,035	-0,293	0,299	0,393	-0,023	0,316	0,015	0,523
p-value	0,007	0,005	0,042	0,82	0,053	0,049	0,008	0,88	0,037	0,921	0
n	44	44	44	44	44	44	44	44	44	44	44

Correlation performed by Spearman's correlation. Data shown in scores obtained in each category of the questionnaires, P300 latency (in milliseconds), P300 amplitude (in microvolts). RE = right ear. LE = left ear; SDQ: Strengths and Difficulties Questionnaire; SNAP: Pelham Scale version IV. *Significant correlation at the 5% level. **Significant correlation at 1% level.

3.7 Prevalence of cognitive and/or behavioral dysfunction

Cognitive and/or behavioral dysfunction was defined as the presence of abnormal results in any SDQ subscale, at least one SNAP-IV domain, or prolonged P300 wave latency. Abnormalities were identified in two children from the control group and eight children in each of the clinical groups. This yielded a dysfunction prevalence of 18.2% among nasal breathers compared to 72.7% among mouth breathers overall, as well as within each mouth-breathing subgroup, with no significant differences based on etiology.

4. Discussion

The data analysis indicates that MBS correlates with cognitive and behavioral dysfunction in children. Notably, there is no significant difference in the performance of mouth breathing children based on etiology. In a study by Kuroishi et al., the evaluation of mouth breathing children, highlights challenges in managing syntactic complexity in written language and numerical operations⁷. These findings suggest a potential link between chronic upper airway obstruction and learning difficulties, as well as suboptimal school performance.

Papapostolou et al. similarly identified impaired neuropsychological performance in children with AR, emphasizing difficulties in working, visual, verbal, and episodic memory, correlated with symptom severity²⁴. ATH, irrespective of obstructive sleep apnea diagnosis, is associated with irritability, aggression, and academic issues. This indicates that mouth breathing by ATH is linked to cognitive and behavioral dysfunction in children²⁵.

These reported findings are consistent with the results observed in the present study, which indicates that MBS is linked to cognitive and behavioral impairments. This association is further supported by the altered outcomes observed across the SDQ and SNAP-IV instruments, as well as neurophysiological abnormalities in P300 recordings.

This study establishes a statistically significant positive correlation between subjective symptom severity—measured by the VAS—and multiple dimensions of child behavior. Heightened symptom perception by parents corresponded to more pronounced emotional, conduct, hyperactivity, and inattention difficulties, as well as an increased burden on the family domain across SDQ and SNAP-IV scores. Crucially, VAS scores also correlated positively with prolonged P300 wave latencies, providing a direct link between subjective perception and objective cognitive dysfunction. Notably, parental perception demonstrated a stronger association with cognitive and behavioral impairments than the anatomical extent of UAO itself. These findings underscore the clinical importance of incorporating parental insights into the evaluation of MBS. Given that cognitive and behavioral monitoring warrants continuous longitudinal follow-up, parents' daily observations serve as a reliable predictive indicator of both severe UAO symptoms and associated neurobehavioral dysfunction.

No significant associations were observed between sociodemographic factors—such as socioeconomic status and parental education—and cognitive or behavioral outcomes. This study was primarily limited by the homogeneity of the sample, which consisted exclusively of children from lower socioeconomic backgrounds representative of the clinical setting where recruitment took place. Furthermore, total inspiratory nasal flow measurements showed no significant intergroup variations and were not correlated with cognitive or behavioral parameters in the evaluated cohort.

A major contribution of the present study is demonstrating that objective electrophysiological findings directly parallel behavioral alterations identified by standardized questionnaires. Prolonged P300 wave latency was strongly associated with elevated scores for inattention, hyperactivity, impulsivity, and conduct problems. This suggests that cognitive dysfunction in children with MBS can be detected through quantifiable objective neurophysiological changes rather than relying solely on subjective reports. This finding is particularly clinically relevant given that P300 recording represents a non-invasive, examiner-independent and feasible neurofunctional assessment in pediatric populations.

Although comprehensive neuropsychological batteries remain the gold standard for cognitive evaluation, they are often time-consuming, highly resource-intensive and limited by reduced availability in primary clinical settings. Conversely, the P300 cognitive evoked potential provides a rapid, objective measure of neural mechanisms underlying attention allocation, working memory and cognitive processing speed. Consequently, it represents a valuable complementary tool for early identification of children at elevated risk for neurobehavioral dysfunction, as well as a reliable objective marker for monitoring cognitive trajectories in longitudinal research.

The precise way mouth breathing induces cognitive and behavioral dysfunction remains unclear. It is hypothesized that episodic hypoxia, sleep disruption, and reduced sleep quality trigger neurochemical changes in the prefrontal cortex and its regulatory subcortical structures, resulting in daytime sleepiness, inattention, fatigue, and executive cognitive dysfunction. Hindering information retention and processing⁹, leading to lower academic performance and an increased need for reinforcement activities^{7,10}.

Given MBS's significant impact on children's cognition and behavior, it's crucial to identify markers for dysfunction risk and severity. Insulin-like growth factor type 1 (IGF-1) is recognized as a neurocognitive damage marker in children²⁶. A study by Key et al. revealed psychoelectrophysiological exam changes, specifically evoked potentials, as early markers for cognitive dysfunction in children with obstructive sleep disorders, proving more sensitive than polysomnography in predicting neurocognitive dysfunction²⁷.

Future studies should prioritize evaluating whether P300 abnormalities resolve following the treatment of MBS and whether electrophysiological recovery directly parallels gains in cognitive and behavioral performance. While airway interventions such as adenotonsillectomy have been shown to partially reverse neurobehavioral deficits in children with obstructive sleep apnea^{28,29}, evidence regarding neurobehavioral recovery remains mixed, with some studies reporting only selective post-surgical improvements³⁰. Within this scope, the P300 cognitive potential emerges as a feasible objective biomarker to identify early neurobehavioral dysfunction and to quantitatively monitor long-term cognitive reversibility following medical or surgical therapies, including adenotonsillectomy and targeted allergic rhinitis treatment.

This study has limitations that warrant consideration. Its cross-sectional design prevents the establishment of direct causal relationships, and the single-center setting with a relatively small sample size may limit the generalizability of the findings. Furthermore, objective sleep measures such as polysomnography were not conducted, as the study was not designed to diagnose obstructive sleep apnea nor to evaluate sleep architecture. Nevertheless, these limitations do not diminish the value of demonstrating objective neurophysiological impairments via P300 latency in this clinical population.

5. Conclusion

MBS was associated with cognitive and behavioral dysfunction in children, regardless of its underlying etiology. Mouth-breathing children demonstrated higher rates of emotional distress, misconduct, hyperactivity, inattention and impulsivity symptoms, as well as prolonged P300 latency when compared with nasal breathers.

The association between prolonged P300 latency and worse behavioral performance reinforces the potential value of electrophysiological assessment as an objective marker of neurobehavioral dysfunction in mouth-breathing children. As a non-invasive and objective measure of cognitive processing, the P300 may represent a useful complementary tool for the evaluation of attention and memory-related dysfunction in mouth-breathing children. Further longitudinal studies are needed to determine the reversibility of these findings following treatment and to clarify the role of P300 as a potential marker of cognitive outcomes in this population.

Declarations

Institutional Review Board Statement

The study was conducted in accordance with the Declaration of Helsinki and approved by the Ethics Committee of the Ethics Committee of Universidade Federal de Minas Gerais (No.57202722.5.0000.5149) on May 17, 2022.

Informed Consent

Statement: Written informed consent was obtained from all subjects involved in the study.

Conflicts of Interest:

The authors declare no conflict of interest.

Funding:

Author Contribution

MST Acquisition, analysis, or interpretation of data; Drafting of the manuscriptLL Substantial contributions to concept or design; Critical review of the manuscript for important intellectual contentLPF Substantial contributions to concept or design; Critical review of the manuscript for important intellectual contentIST Acquisition, analysis, or interpretation of data; Drafting of the manuscriptHMGB Substantial contributions to concept or design; Critical review of the manuscript for important intellectual contentAll authors reviewed the manuscript.

References

1. Felcar JM, Bueno IR, Massan ACS, Torezan RP, Cardoso JR. Prevalência de respiradores bucais em crianças de idade escolar. *Ciência & Saúde Coletiva* Mar. 2010;15:437–44. <https://doi.org/10.1590/S1413-81232010000200020>.
2. Lima MS, Nader CMFF, Franco LP, Meira ZMA, Capanema FD, Guimarães RES, et al. Pulmonary hypertension evaluation by Doppler echocardiogram in children and adolescents with mouth breathing syndrome. *Brazilian J Otorhinolaryngology* May. 2017;83(3):292–8. <https://doi.org/10.1016/j.bjorl.2016.03.020>.
3. Motonaga SM, Berte LC, Anselmo-Lima WT. Mouth breathing: Causes and changes of the stomatognathic system. *Revista Brasileira de Otorrinolaringologia* Aug. 2000;66(4):373–9.
4. Testa D, Di Bari M, Nunziata M, De Cristofaro G, Massaro G, Marcuccio G, et al. Allergic rhinitis and asthma assessment of risk factors in pediatric patients: A systematic review. *International J Pediatr Otorhinolaryngology* Feb. 2020;129:109759. <https://doi.org/10.1016/j.ijporl.2019.109759>.
5. Meltzer EO, Blaiss MS, Derebery MJ, Mahr TA, Gordon BR, Sheth KK, et al. Burden of allergic rhinitis: Results from the Pediatric Allergies in America survey. *Journal of Allergy and Clinical Immunology*. Set. 2009;124(3):S43–70. <https://doi.org/10.1016/j.jaci.2009.05.013>.
6. Pereira L, Monyror J, Almeida FT, Almeida FR. Prevalence of adenoid hypertrophy: A systematic review and meta-analysis. *Sleep Med Reviews* Apr. 2018;38:101–12. <https://doi.org/10.1016/j.smrv.2017.06.001>.
7. Kuroishi RCS, Garcia RB, Valera FCP, Anselmo-Lima WT, Fukuda MTH. Deficits in working memory, reading comprehension and arithmetic skills in children with mouth breathing syndrome: analytical cross-sectional study. *Sao Paulo Med Journal* Sep. 2014;133(2):78–83. <https://doi.org/10.1590/1516-3180.2013.7630011>.
8. Brockmann PE, Gozal D. Neurocognitive consequences in children with sleep disordered breathing: Who is at risk? *Children*. Aug. 2022;9(9):1278. <https://doi.org/10.3390/children9091278>.
9. Smith DL, Gozal D, Hunter SJ, Philby MF, Kaylegian J, Kheirandish-Gozal L. Impact of sleep disordered breathing on behaviour among elementary school-aged children: a cross-sectional analysis of a large community-based sample. *European Respiratory Journal* Dec. 2016;48(6):1631–9. <https://doi.org/10.1183/13993003.00808-2016>.
10. Yamasaki A, Burks CA, Bhattacharyya N. Cognitive and quality of life-related burdens of illness in pediatric allergic airway disease. *Otolaryngology–Head and Neck Surgery*. Mar. 2020;162(4):566–71. <https://doi.org/10.1177/0194599820908202>.
11. Ribeiro GCA, Santos ID, Santos ACN, Paranhos LR, C'sar CPHAR. Influence of the breathing pattern on the learning process: a systematic review of literature. *Brazilian J Otorhinolaryngology* Jul. 2016;82(4):466–78. <https://doi.org/10.1016/j.bjorl.2015.08.026>.
12. Zapletal A, Chapulová J. Nasal airflow and resistance measured by active anterior rhinomanometry in healthy children and adolescents. *Pediatric Pulmonology*. Feb. 2002;33(3):174–80. <https://doi.org/10.1002/ppul.10066>.
13. Nevis IF, Binkley K, Kabali C. Diagnostic accuracy of skin-prick testing for allergic rhinitis: a systematic review and meta-analysis. *Allergy Asthma Clin Immunol*. 2016 Apr 27;12:20. 10.1186/s13223-016-0126-0. PMID: 27127526; PMCID: PMC4848807. <https://doi.org/10.1186/s13223-016-0126-0>.
14. Group MSB. On behalf of the allergic rhinitis and impairment issues in schoolchildren: a consensus report. *Current Med Res Opinion* Nov. 2004;20(12):1937–52. <https://doi.org/10.1185/030079904x13266>.
15. Amiri S, AbidolahiFakhim S, Lofti A, Bayazian G, Sohrabpour M, Hemmatjoo T. Effect of adenotonsillectomy on ADHD symptoms of children with adenotonsillar hypertrophy and sleep disordered breathing. *International J Pediatr Otorhinolaryngology* Aug. 2015;79(8):1213–7. <https://doi.org/10.1016/j.ijporl.2015.05.015>.
16. Francés L, Quintero J, Fernández A, Ruiz A, Caules J, Fillon G, et al. Current state of knowledge on the prevalence of neurodevelopmental disorders in childhood according to the DSM-5: a systematic review in accordance with the PRISMA criteria. *Child Adolesc Psychiatry Mental Health* Mar. 2022;16(1). <https://doi.org/10.1186/s13034-022-00462-1>.
17. Costa EC Jr., Sabino HAC, Miura CS, Azevedo CB, Menezes UP, Valera FCP, et al. Atopy and adenotonsillar hypertrophy in mouth breathers from a reference center. *Brazilian J Otorhinolaryngology* Nov. 2013;79(6):663–7. <https://doi.org/10.5935/1808-8694.20130123>.
18. Brodsky L. Modern assessment of tonsils and adenoids. *Pediatric Clinics of North America*. Dec. 1989;36(6):1551–69. [https://doi.org/10.1016/s0031-3955\(16\)36806-7](https://doi.org/10.1016/s0031-3955(16)36806-7).
19. Barros JRC, Becker HMG, Pinto JA. Avaliação de atopia em crianças respiradoras bucais atendidas em centro de referência. *Jornal de Pediatria* Dez. 2006;82:458–64. <https://doi.org/10.1590/S0021-75572006000800011>.
20. Silva TBF, Osório FL, Loureiro SR. SDQ: discriminative validity and diagnostic potential. *Frontiers in Psychology*. Jun. 2015;6. <https://doi.org/10.3389/fpsyg.2015.00811>.

21. Costa DS, Paula JJ, Malloy-Diniz FL, Romano-Silva MA, Miranda DM. Parent SNAP-IV rating of attention-deficit/hyperactivity disorder: accuracy in a clinical sample of ADHD, validity, and reliability in a Brazilian sample. *Jornal de Pediatria* Nov. 2019;6:736–43. <https://doi.org/10.1016/j.jped.2018.06.014>.
22. Boucher O, Bastien CH, Muckle G, Saint-Amour D, Jacobson SW, Jacobson JL. Behavioural correlates of the P3b event-related potential in school-age children. *Int J psychophysiology: official J Int Organ Psychophysiology* Jun. 2010;76(3):148–57. <https://doi.org/10.1016%2Fj.ijpsycho.2010.03.005>.
23. Fuchigami T, Okubo O, Fujita Y, Okuni M. Auditory event-related potentials and reaction time in children evaluation of cognitive development. *Developmental Med & Child Neurology* Nov. 2008;35(3):230–7. <https://doi.org/10.1111/j.1469-8749.1993.tb11627.x>.
24. Papapostolou G, Kiotseridis H, Romberg K, Dahl A, Bjermer L, Lindgren M, et al. Cognitive dysfunction and quality of life during pollen season in children with seasonal allergic rhinitis. *Pediatric Allergy Immunology* Aug. 2020;32(1):67–76. <https://doi.org/10.1111/pai.13328>.
25. Kurnatowski P, Putynski L, Lapienis M, Kowalska B. Neurocognitive abilities in children with adenotonsillar hypertrophy. *International J Pediatr Otorhinolaryngology* Mar. 2006;70(3):419–24. <https://doi.org/10.1016/j.ijporl.2005.07.006>.
26. Shi Y, Luo H, Liu H, Hou J, Feng Y, Chen J, et al. Related biomarkers of neurocognitive impairment in children with obstructive sleep apnea. *International J Pediatr Otorhinolaryngology* Jan. 2019;116:38–42. <https://doi.org/10.1016/j.ijporl.2018.10.015>.
27. Key APF, Molfese DL, O'Brien L, Gozal D. Sleep-disordered breathing affects auditory processing in 5–7-year-old children: Evidence from brain recordings. *Developmental Neuropsychology* Sep. 2009;34(5):615–28. <https://doi.org/10.1080/87565640903133608>.
28. Di Mauro P, Cocuzza S, Maniaci A, Ferlito S, Rasà D, Anzivino R, et al. The effect of adenotonsillectomy on children's behavior and cognitive performance with obstructive sleep apnea syndrome: State of the Art. *Children* Oct. 2021;8(10):921. <https://doi.org/10.3390%2Fchildren8100921>.
29. Shan S, Wang S, Yang X, Liu F, Xiu L. Effect of adenotonsillectomy on the growth, development, and comprehensive cognitive abilities of children with obstructive sleep apnea: a prospective single-arm study. *BMC Pediatrics* Jan. 2002;22(1). <https://doi.org/10.1186/s12887-022-03111-w>.
30. Taylor HG, Bowen SR, Beebe DW, Hodges E, Amin R, Arens R, et al. Cognitive effects of adenotonsillectomy for obstructive sleep apnea. *Pediatrics* Aug. 2016;138(2). <https://doi.org/10.1542/peds.2015-4458>.
31. Disclaimer/Publisher's Note. The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s).