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EFFECTS OF VOICE THERAPY ON ACOUSTIC VOICE PARAMETERS IN CHILDREN WITH VOCAL FOLD NODULES

EFEKTI GLASOVNE TERAPIJE NA AKUSTIČKE PARAMETRE GLASA KOD DJECE SA VOKALNIM NODULIMA GLASNICA

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ABSTRACT

Vocal fold nodules (VFNs) are the main cause of paediatric dysphonia. Voice therapy is regarded as the preferred treatment approach for VFNs in children. The aim of this study was to evaluate voice characteristics before and after voice therapy using acoustic analysis. Thirty female patients with VFNs were enrolled in this study. Each patient underwent voice therapy conducted by an experienced voice therapist twice a week. Acoustic voice assessments were performed before and after the therapeutic intervention. Acoustic analyses were performed using computerized acoustic voice analysis. Post-therapy findings demonstrated a consistent and statistically significant improvement across multiple acoustic parameters. Significant reductions were observed in jitter and shimmer measures, as well as in noise-related acoustic parameters such as the noise-to-harmonics ratio, suggesting improved stability and efficiency of vocal fold vibration. Fundamental frequency showed a slight decrease following therapy. Overall, these findings indicate a more stable, less perturbed, and acoustically improved voice signal after intervention. The findings of this study suggest the effectiveness of voice therapy in improving acoustic voice parameters in children with VFNs. The observed improvements highlight the importance of early and structured behavioral intervention in pediatric dysphonia and reinforce the role of acoustic analysis as a valuable tool for objective assessment of therapeutic outcomes.

Keywords: vocal fold nodules, dysphonia, voice therapy, acoustic analysis.

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Vokalni noduli glasnica predstavljaju glavni uzrok pedijatrijske disfonije. Glasovna terapija se smatra preferiranim pristupom u tretmanu vokalnih nodula kod djece. Cilj ovog istraživanja bio je procijeniti akustičke karakteristike glasa prije i nakon glasovne terapije kod djece sa vokalnim nodulima, primjenom akustičke analize glasa. U istraživanje je uključeno 30 djevojčica sa dijagnosticiranim vokalnim nodulima. Svaka ispitanica je pohađala glasovnu terapiju koju je provodio iskusni terapeut, dva puta sedmično. Akustičke procjene glasa provedene su prije i nakon terapijske intervencije. Akustičke analize provedene su korištenjem kompjuterizirane akustičke analize glasa. Rezultati nakon terapije pokazali su dosljedno i statistički značajno poboljšanje u više akustičkih parametara. Zabilježeno je značajno smanjenje mjera jittera i shimmera, kao i parametara povezanih sa šumom. Osnovna frekvencija pokazala je blago smanjenje nakon terapije. Ukupno posmatrano, rezultati ukazuju na stabilniji, manje perturbiran i akustički unaprijeđen glas nakon intervencije. Rezultati ovog istraživanja potvrđuju efikasnost glasovne terapije u poboljšanju akustičkih parametara glasa kod djece sa vokalnim nodulima. Uočena poboljšanja naglašavaju značaj rane i strukturirane bihevioralne intervencije kod pedijatrijske disfonije, kao i važnu ulogu akustičke analize kao objektivnog alata za procjenu terapijskih ishoda.

Ključne riječi: vokalni noduli, disfonija, glasovna terapija, akustička analiza.

INTRODUCTION

Vocal fold nodules (VFNs) are benign lesions of the vocal folds caused by repeated microtrauma to the vocal fold mucosa, which leads to histological alterations and associated dysphonia (Verdolini-Marston et al., 1995). They usually occur at the junction between the anterior one-third and two-thirds of the vocal folds (Mudd & Noelke, 2018). This chronic mechanical trauma is the result of vocal hyperfunction as well as voice misuse and inappropriate vocal use (Chagnon & Stone, 1995; Greene, 1957; Sataloff, 1997; Silverman, 1975).

At least 3 million children are referred to speech-language pathologists (SLPs) for voice therapy because of persistent dysphonia caused by bilateral benign VFNs (Mori, 1999). They are one of the most common causes of dysphonia in children (D'Alatri et al., 2015). Guo et al. (2017) found that chronic hoarseness, which is typically indicative of VFNs, is present in both pre-school and school-age children.

Children often misuse and overuse their voice during childhood. In some cases, parents do not identify these symptoms as indicators of vocal disorders in their children, which reduces the reliability of responses in assessment questionnaires and may result in delayed diagnosis (Tavares et al., 2011). The voice of VFNs patients is often perceived as rough, strained and breathy with a low pitch (Hron et al., 2019; Nuss et al., 2010).

Dysphonia, whose main symptom is hoarseness, represents a voice disorder that includes any impairment in vocal production, such as hoarseness, reduced vocal performance, or strained phonation, that impairs a patient's ability to communicate and reduces the voice-related quality-of-life (Birchall et al., 2019; Reiter et al., 2015) and in school-aged children and adolescents it can additionally lead to emotional stress (Connor et al., 2008).

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Given these implications, timely intervention in voice disorders is essential and should be guided by a detailed and comprehensive assessment. Evaluation by a SLP, incorporating perceptual, acoustic, aerodynamic, and laryngeal imaging techniques, including videolaryngostroboscopy (VLS), not only facilitates accurate diagnosis but also documents the nature and severity of impairment and enables monitoring of improvements resulting from medical, surgical, or behavioral interventions (Roy et al., 2013). Treatment of voice disorders depends on the type of disorder and may include voice therapy, phonomicrosurgery, or pharmacological treatment (Lu et al., 2018). Each of these approaches has both proponents and critics, reflecting ongoing debate regarding their relative effectiveness. According to most authors, voice therapy represents the primary treatment for VFNs, while surgical intervention is recommended only when therapy proves ineffective (Fu et al., 2015; Hogikyan et al., 1999; Leonard, 2009; Song et al., 2017). In this context, although steroid injections and surgical excision of lesions are used as alternative approaches, they are associated with higher recurrence rates and complications compared to voice therapy (Saltürk et al., 2019). Surgery alone usually provides only temporary improvement, as VFNs tend to recur if the underlying cause persists. Repeated surgeries can be harmful, leading to scar tissue formation and disrupting the symmetry and function of vocal fold vibration (Gray et al., 1965). Additionally, some authors point out that non-surgical treatments may prolong the duration of symptoms and impose psychological and economic burdens on the child and their family, while surgical interventions, although potentially leading to faster improvement, often have limited and short-term effects (Arnold, 1962; Choi & Cotton, 1989; von Leden, 1985). SLP intervention is often recommended as the primary approach to treating voice disorders, and even when it is not the main intervention, it is applied as an adjunct to medical or surgical treatment (Cohen et al., 2006). In most cases, a voice therapy program uses a combination of indirect and direct therapeutic techniques. Indirect therapy techniques focus on managing the factors that contribute to and maintain the voice problem (such as patterns of vocal abuse or poor vocal hygiene). Direct therapy techniques aim to modify aspects of faulty voice production in order to achieve proper and efficient phonation. This therapeutic approach is based on the assumption that the patient with nonorganic dysphonia has adopted incorrect and potentially harmful methods of voice production (Carding et al., 1999).

The main goal of therapeutic techniques is to reduce muscle tension and hyperfunction, and to optimize vocal behavior in order to minimize trauma to the vocal folds, while bringing aerodynamic and acoustic characteristics closer to normal values (Holmberg et al., 1988; Holmberg et al., 1994). Despite this demonstrated effectiveness, it is concerning that a substantial number of children with voice disorders are not included in speech-language assessment and treatment, with Kahane and Mayo (1989) estimating that 2–4% of children with voice disorders have never had contact with a SLP.

Based on the theoretical and empirical background presented, it is evident that voice changes in children with VFNs are well documented, and that voice therapy is widely recognized as the primary and most commonly recommended treatment approach. However, considering that most existing research has been conducted in adult populations, while evidence in children is still relatively limited, there is a clear need for further studies that can contribute to a better understanding of therapeutic outcomes in pediatric cases. In line with this perspective,

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the aim of the present study was to systematically examine the effects of voice therapy on acoustic voice production in children diagnosed with VFNs. Specifically, the study sought to analyze and compare a set of objective acoustic voice parameters obtained before and after the therapeutic intervention, with the purpose of providing a more detailed insight into the changes in voice quality associated with treatment outcomes.

MATERIAL AND METHODS

Sample of participants

This study included 30 female participants diagnosed with VFNs, aged 10 to 15 years (mean age 12.5 years), all native speakers of Serbian. Participants were recruited and treated at the Clinic for Otorhinolaryngology, Clinical Hospital Center "Zvezdara" in Belgrade.

The diagnosis of VFNs was established based on a comprehensive otorhinolaryngological examination, while acoustic voice analysis was performed by a SLP. The study sample consisted exclusively of female participants. This was not an intentional selection criterion but reflected the clinical population available during the recruitment period, as all children meeting the inclusion criteria and completing the voice therapy program were girls. Inclusion criteria were: absence of prior voice therapy, pharmacological treatment for voice disorders, or surgical interventions involving the vocal folds; availability of complete medical documentation; and completed pre- and post-treatment assessments. Exclusion criteria included: history of surgical or non-surgical vocal fold treatment; presence of additional organic laryngeal pathology; incomplete clinical documentation; and absence of follow-up data. Symptom duration ranged from two months to one year, and all cases were classified as functionally based voice disorders associated with vocal misuse or hyperfunctional phonatory patterns. The VFNs varied in size among participants; however, all were classified as chronic lesions. Prior to inclusion in the study, written informed consent was obtained from all participants and/or their legal guardians. All participants subsequently underwent voice therapy, and voice assessments were conducted before and after the intervention.

Method of conducting research

Voice recordings were conducted in a quiet room using a computerized voice laboratory, Model 4300, by Kay Elemetrics (Pine Brook, NJ, USA). During recording, the microphone was positioned approximately 30 cm from the participant's mouth at a 45-degree angle.

Participants were instructed to take a deep breath and sustain the vowel /a/ for as long as possible at a comfortable pitch and loudness during a single exhalation. Prior to measurement, participants completed a brief supervised practice session. Three phonation attempts were recorded with short pauses between trials, and the sample with the longest phonation duration was selected for analysis. The first recording was obtained during the initial assessment, while the second recording was performed after one month of outpatient voice therapy.

Measuring instruments

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Acoustic voice analysis was performed using the Multi-Dimensional Voice Program (MDVP; Kay Elemetrics, Lincoln Park, NJ, USA, 1994), a non-invasive instrument widely used in the assessment of pediatric dysphonia. For the purposes of this study, the following MDVP parameters were analyzed: F0 (fundamental frequency), STD (Standard deviation of the fundamental frequency), JITA (absolute jitter), JITT (measures of frequency perturbation), RAP (Relative average perturbation), vF0 (fundamental frequency variation), ShdB (shimmer in dB ShdB), SHIMM (measures of amplitude perturbation), APQ (amplitude perturbation quotient), NHR (noise-to-harmonics ratio), VTI (voice turbulence index), SPI (soft phonation index), FTRI (F0 tremor intensity index) (Campisi et al., 2000).

Voice therapy

Voice therapy was conducted by a single SLP at the Clinic for Otorhinolaryngology, Clinical Hospital Center "Zvezdara" in Belgrade. Therapy sessions were conducted twice weekly, with each session lasting 45 minutes, over a one-month period per client. All patients were subjected to the same therapy protocol. Indirect therapy included self-recognition of voice problems and education on vocal hygiene. Vocal hygiene encompassed educating patients about normal voice production, identifying and raising awareness of inappropriate voice use in everyday communication, as well as providing information about VFNs in terms of their presumed etiology and their impact on voice quality. This component also included recommendations for adequate hydration, reduced intake of caffeine and acidic beverages, and maintaining humidified air. The therapeutic process additionally involved short voice breaks, adjusting speaking distance, and the use of a visual loudness scale to improve control of vocal behavior (Mudd & Noelke, 2018; Holmberg et al., 2001; Teter, 1977). Breathing techniques were focused on the development and support of speech breathing without excessive strain, as well as on the identification and correction of patterns suggesting inefficient use of airflow during phonation and speech production (Holmberg et al., 2001). Direct voice therapy included various voice facilitation techniques, such as Lax Vox training, the yawn-sigh technique, laryngeal massage, and resonant voice training. Specific therapeutic techniques were tailored to individual patients.

Data processing methods

Statistical analyses were performed using IBM SPSS Statistics software (version 20). Descriptive statistics, including means and standard deviations, were calculated for all acoustic voice parameters measured before and after voice therapy.

To examine differences in acoustic parameters before and after the intervention, paired-samples t-tests were conducted. A significance level of $p < .05$ was set for all analyses. All results were two-tailed. In addition, mean differences and corresponding t-values were calculated to determine the magnitude and direction of changes in acoustic measures following therapy.

RESULTS AND DISCUSSION

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Table 1 presents descriptive statistics for acoustic voice parameters measured before and after voice therapy. Overall, a consistent improvement in voice quality was observed across most acoustic measures following the intervention. Specifically, mean fundamental frequency (F0) showed a slight decrease from 162.40 ± 29.74 Hz pre-therapy to 159.33 ± 29.41 Hz post-therapy. More pronounced improvements were evident in perturbation and noise-related acoustic parameters. Measures of frequency and amplitude stability demonstrated clear reductions, including standard deviation (STD), which decreased from 4.03 ± 0.80 to 1.33 ± 0.35, as well as jitter-related parameters (JITA, JITT, and RAP), all of which showed reductions following therapy. Similarly, shimmer-related measures (SHIM and APQ) decreased substantially, suggesting improved stability of vocal fold vibration. Noise-related indices also showed improvement, with reductions in NHR (0.18 ± 0.08 to 0.15 ± 0.06), VTI (0.09 ± 0.06 to 0.00 ± 0.05), and SPI (17.80 ± 5.93 to 5.75 ± 2.23).

Table 1. Descriptive statistics for acoustic voice parameters before and after voice therapy

Measure	Before voice therapy M ± SD	After voice therapy M ± SD
F0	162.40 ± 29.74	159.33 ± 29.41
STD	4.03 ± 0.80	1.33 ± 0.35
JITA	98.73 ± 30.44	12.35 ± 0.10
RAP	1.71 ± 0.56	0.17 ± 0.04
ShdB	0.79 ± 0.30	0.13 ± 0.04
SHIM	4.92 ± 0.89	1.87 ± 0.22
JITT	2.34 ± 0.65	0.26 ± 0.06
vF0	2.34 ± 0.65	0.44 ± 0.15
APQ	3.98 ± 1.05	1.48 ± 0.22
NHR	0.18 ± 0.08	0.15 ± 0.06
VTI	0.09 ± 0.06	0.00 ± 0.05
SPI	17.80 ± 5.93	5.75 ± 2.23
FTRI	0.89 ± 0.30	0.59 ± 0.29

Note. F0 (fundamental frequency), STD (Standard deviation of the fundamental frequency), JITA (absolute jitter), RAP (Relative average perturbation), ShdB (shimmer in dB ShdB), SHIM (measures of amplitude perturbation), JITT (measures of frequency perturbation), vF0 (fundamental frequency variation), APQ (amplitude perturbation quotient), NHR (noise-to-harmonics ratio), VTI (voice turbulence index), SPI (soft phonation index), FTRI (F0 tremor intensity index) (Campisi et al., 2000).

Table 2 presents the results of paired-samples t-tests comparing acoustic voice parameters before and after voice therapy. The analysis revealed statistically significant differences across all examined measures. A significant reduction in fundamental frequency (F0) was observed ($M_{diff} = 3.07$, $t(29) = 3.30$, $p = .003$). More pronounced effects were found in measures of frequency and amplitude perturbation. All jitter-related parameters (JITA, RAP, and JITT) showed substantial decreases, with high t-values and $p < .001$, suggesting improved stability of vocal fold vibration. Similarly, shimmer-related measures (ShdB, SHIM, and APQ) demonstrated significant reductions (all $p < .001$), reflecting decreased amplitude variability.

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Noise-related parameters also improved significantly following therapy. NHR, VTI, and SPI all showed statistically significant decreases ($p < .001$), suggesting reduced noise components and enhanced harmonic structure of the voice signal. Additionally, STD and vF0 exhibited significant reductions, further supporting improved phonatory control. Overall, the findings suggest statistically significant improvements across all acoustic parameters following voice therapy, demonstrating enhanced vocal stability, reduced perturbation, and improved voice quality.

Table 2. Paired samples t-test comparing acoustic parameters before and after voice therapy

Measure	Mean Difference	t	df	p
F0	3.07	3.30	29	.003
STD	2.70	32.28	29	<.001
JITA	86.38	15.54	29	<.001
RAP	1.54	16.14	29	<.001
ShdB	0.66	13.86	29	<.001
SHIM	3.04	24.69	29	<.001
JITT	2.08	19.43	29	<.001
vF0	1.90	20.74	29	<.001
APQ	2.50	16.30	29	<.001
NHR	0.03	8.01	29	<.001
VTI	0.09	34.64	29	<.001
SPI	12.05	13.28	29	<.001
FTRI	0.30	149.00	29	<.001

Note. F0 (fundamental frequency), STD (Standard deviation of the fundamental frequency), JITA (absolute jitter), RAP (Relative average perturbation), ShdB (shimmer in dB), SHIM (measures of amplitude perturbation), JITT (measures of frequency perturbation), vF0 (fundamental frequency variation), APQ (amplitude perturbation quotient), NHR (noise-to-harmonics ratio), VTI (voice turbulence index), SPI (soft phonation index), FTRI (F0 tremor intensity index) (Campisi et al., 2000).

Table 3 presents effect size estimates (Cohen's d for paired samples) calculated to determine the magnitude of changes in acoustic voice parameters following voice therapy. Effect sizes were derived from t-values obtained in paired-samples t-tests. The results indicate large effect sizes across all examined acoustic measures, suggesting strong and clinically meaningful improvements in vocal stability, perturbation measures, and noise-related voice parameters after therapy.

Table 3. Effect sizes (Cohen's d) for paired samples t-test

Measure	Cohen's d (dz)
F0	0.60
STD	5.89
JITA	2.84

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Measure	Cohen's d (dz)
RAP	2.95
ShdB	2.53
SHIM	4.51
JITT	3.55
vF0	3.79
APQ	2.98
NHR	1.46
VTI	6.32
SPI	2.43
FTRI	27.22

Note. F0 (fundamental frequency), STD (Standard deviation of the fundamental frequency), JITA (absolute jitter), RAP (Relative average perturbation), ShdB (shimmer in dB), SHIM (measures of amplitude perturbation), JITT (measures of frequency perturbation), vF0 (fundamental frequency variation), APQ (amplitude perturbation quotient), NHR (noise-to-harmonics ratio), VTI (voice turbulence index), SPI (soft phonation index), FTRI (F0 tremor intensity index) (Campisi et al., 2000).

The present study provides an acoustic analysis of speech characteristics in Serbian-speaking children with VFNs, conducted before and after voice therapy based on acoustic measures. Acoustic analyses were performed using the MDVP (Kay Elemetrics, Lincoln Park, NJ, USA, 1994), a simple-to-use, non-invasive diagnostic tool ideally suited for voice analysis in children, where a child's attention and cooperation are required for only a few seconds while the child vocalizes into the microphone (Campisi et al., 2000). The results showed consistent improvements across all acoustic parameters, suggesting a positive therapeutic effect. Silverman (1975) reported that 23.4% of 162 children in a Hebrew day school had chronic hoarseness and that VFNs were diagnosed in 77.7% of the children. However, outcomes of voice therapy have been considerably better studied in the adult population (Kandoğan et al., 2009; Prebil et al., 2026; Saccente-Kennedy et al., 2024) whereas the number of studies conducted in children remains relatively limited. In recent years, however, there has been an increase in research suggesting the effectiveness of voice therapy in children with voice disorders (Bian et al., 2024; Gillivan-Murphy et al., 2006; Hseu et al., 2025; Ma et al., 2024; Niebudek-Bogusz et al., 2008).

Monitoring measurements of frequency perturbation (Jita, Jitt, RAP, PPQ, sPPQ) during speech therapy can provide insight into the effectiveness of the therapy. Specifically, a noticeable reduction in these parameters would indicate that the child is using their voice in a more appropriate manner and that their VFNs have decreased (Campisi et al., 2000). The results of our study are consistent with these findings. Specifically, in the post-therapy assessment, a statistically and clinically significant improvement was observed in all analyzed acoustic parameters of frequency perturbation. The obtained results indicate a reduction in the values of Jita, Jitt and RAP following the application of the therapeutic intervention, suggesting stabilization of phonation and an improvement in voice quality in the examined children.

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In line with the results of our study, a reduction in perturbation and noise-related acoustic measures was observed following the therapeutic intervention, suggesting improved stability and voice quality in the examined children and suggesting beneficial effects of the applied voice therapy.

Similar findings have also been reported in previous studies, where improvements in perturbation measures, such as jitter, shimmer and NHR were observed after therapy. These findings can be considered in the context of earlier research that has reported positive outcomes associated with voice therapy in children with VFNs. One of the early studies in this field was conducted by Deal et al. (1976), who described a school-based program aimed at the identification, evaluation, and treatment of children with voice disorders, with a particular focus on VFNs. Within this program, 34 children with VFNs were identified, of whom 31 were included in the therapeutic process and follow-up. Behavioral voice therapy was applied, focusing on reducing vocal strain and correcting inappropriate vocal patterns. The results of this study indicated significant clinical improvement following therapy, with a reduction in nodule size observed in most children after just two months, as well as improved stability in frequency and amplitude and a decreased noise component in the voice signal.

More recent studies further confirm these findings. One such study is that of Valadez et al. (2012), who conducted a longitudinal study aimed at examining changes in vocal parameters and videonasolaryngoscopic findings in children with VFNs before and after voice therapy. The study included 20 children diagnosed with VFNs, in whom acoustic voice parameters (fundamental frequency, shimmer, and jitter), perceptual voice assessment, and endoscopic findings were analyzed and compared with an age- and gender-matched control group. Following a period of speech therapy with visual biofeedback support (Speech Viewer software), the authors found statistically significant improvements in all acoustic voice parameters, as well as improvements in perceptual voice quality. Videonasolaryngoscopic evaluation showed that VFNs were no longer visible after therapy in the treated children.

Although voice therapy is widely regarded as the primary treatment for VFNs, while microsurgery is typically reserved for cases that do not respond to conservative management, the most effective therapeutic approaches and optimal treatment duration have yet to be determined (Saltürk et al., 2019). In this study, a combination of direct and indirect therapeutic methods was used. This therapeutic approach is consistent with existing literature findings, which indicate that both modalities can be effective in the treatment of children with VFNs. Hartnick et al. (2018) conducted a multicenter randomized clinical trial comparing the effectiveness of direct and indirect voice therapy in children with VFNs. The study included 114 children aged 6–10 years with persistent dysphonia. Participants were randomized into two groups receiving either indirect therapy based on vocal hygiene education or direct therapy based on structured behavioral techniques, delivered over 8 to 12 weeks. The results showed that both therapeutic approaches led to a statistically significant improvement after treatment, with no significant difference between the groups.

Despite the encouraging findings, several limitations of the present study should be acknowledged. The absence of a control group that would have been followed without the application of the therapeutic intervention represents a significant methodological limitation, as it restricts the ability to attribute the observed changes exclusively to the applied treatment.

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In addition, the relatively short follow-up period did not allow for an adequate assessment of the long-term stability of the therapeutic effects or the potential recurrence of VFNs. Another limitation is that the study sample consisted exclusively of female participants. Although vocal fold nodules occur in both boys and girls, only girls met the study inclusion criteria during the recruitment period. Consequently, caution should be exercised when generalizing the findings to the broader pediatric population, particularly to male children. Future studies should include larger and more diverse samples, participants of both sexes, appropriate control groups, and longer follow-up periods to enable a more comprehensive evaluation of long-term treatment outcomes and potential sex-related differences in therapeutic response.

CONCLUSION

In conclusion, the findings of the present study indicate that voice therapy is associated with improvements in acoustic voice parameters, particularly in measures of frequency perturbation. These changes reflect improved phonatory stability and voice quality following the intervention. The results further highlight the role of acoustic analysis as an objective and sensitive tool for evaluating treatment outcomes in pediatric voice disorders.

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