The Influence of Auditory Feedback and Vocal Rehabilitation on Prelingual Hearing-Impaired Individuals Post Cochlear Implant

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Abstract: Objective. To verify changes in the perceptual and acoustic vocal parameters in prelingual hearing-impaired adults with cochlear implants after vocal rehabilitation.

Hypothesis. Auditory feedback restoration alone after cochlear implant is not enough for vocal adjustments. A targeted and specific voice therapy intervention is required.

Study Design. Prospective and pre−post repeated measures design.

Methods. Twenty literate adults with severe to profound prelingual bilateral sensorineural hearing loss participated in the study; individuals were implanted late and were fluent users of oral language. Ages ranged from 17 to 48 years. All individuals presented normal results in laryngoscopy, and hearing thresholds with the cochlear implant were over 40 dB HL. Individuals were randomly distributed into two groups: Group 1 (treatment group) and Group 2 (control group), both with ten patients each, five men and five women, matching mean age and hearing deprivation time before the cochlear implantation. Patients from Group 1 underwent a protocol of vocal therapy including 12 individual sessions with the same clinician. Group 2 only underwent vocal recordings. The vocal recordings occurred before and after the participation in the therapy protocol for Group 1 and after the same period, 3 months later, without any intervention, for Group 2. The recording sessions used the Consensus Auditory-Perceptual Evaluation of Voice protocol sentence reading and emission of sustained vowel /a/. Auditory-perceptual evaluation of voices was performed by three judges, and the acoustical analysis used the *Praat* program.

Results. Statistically significant reductions in the overall vocal degree, vocal instability, and degree of resonance change were observed after vocal rehabilitation in Group 1. Statistically, individuals from Group 1 did not differ in regard to the modification of acoustic parameters. Group 2 did not present significant changes in any of the analyzed parameters.

Conclusions. The cochlear implanted adults submitted to vocal rehabilitation presented changes in the auditory-perceptual parameters, with reduction of the overall voice severity, vocal instability, and degree of resonance after vocal intervention. There were no changes in the acoustic parameters in the implanted prelingual hearing-impaired adult subjects.

Key Words: Voice−Hearing Loss−Cochlear Implantation−Rehabilitation−Adult.

INTRODUCTION

Speech and voice production is made up of four phases: respiration, phonation, articulation, and resonance. However, the auditory feedback mechanism also plays an important role.[1] The auditory system is an essential component for the development and maintenance of voice and speech quality.[2,3] The auditory system offers two types of control: *feedback* and *feedforward*. Auditory *feedback* plays three roles: (a) provides frequency and intensity adjustments, as well as other adjustments that may affect speech intelligibility; (b) provides information on environmental conditions that may affect vocal quality; (c) contributes to the production of internal referrals of *feedforward* planning. The *feedforward* system uses previously acquired internal references to control voice and speech speed, without relying on real-time and constant auditory *feedback*.[4] Auditory alterations may interfere with building adjustments or with the proper use of the structures involved in speech and voice production due to the lack of quality or adequacy of auditory *feedback*. The vocal changes found in the hearing impaired are usually related to breathing, phonation, and articulation. These changes may vary according to the type and degree of hearing loss, as well as the time of hearing loss, whether before or after language and speech development as well as motor and sensory pathways involvement.[4,5]

The speech and voice alterations of individuals with prelingual hearing impairment are more pronounced than the ones found in individuals with postlingual deafness. Individuals with prelingual hearing impairment have had no auditory experience and an immature neuromuscular phonatory control, which controls the muscles involved in vocal production, favoring the adequate production of voice,

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phonemes, and articulation.[5–7] The auditory *feedback* restriction has negative impacts on the auditory-perceptual and acoustic parameters of the voice of the hearing impaired. Such negative impacts include reduced vocal quality, fundamental frequency (f_o) deviations, unstable voice, alteration in formant frequencies, and changes in resonance and speech production. Thus, overall voice changes related to the source and the filter of the vocal production are seen.[4,8–14] Studies strongly suggest that these patients have difficulty with subglottic pressure and vocal fold tension, which results in a reduced speed in vocal fold adduction and rapid vocal fold abduction. Hearing-impaired patients also present with reduced speech intelligibility due to limited pneumo-phono articulatory coordination, causing the individual to take more pauses during the emission.[4,15,16]

Cochlear implants (CIs) have shown benefits for voice improvement. However, some vocal parameters may not be susceptible to modification through the restoration of auditory feedback and auditory perception only. This approach may be especially insufficient in individuals with longer standing hearing impairment and more extensive vocal changes because of deafness. For this reason, the authors' consideration of the need for specific speech therapy focusing on vocal parameters is imperative after CI.[17]

Voice exercises, part of the direct approaches for voice rehabilitation, are used in the voice clinic as tools for changing the phonation pattern. Voice therapy involves structured treatment sessions aimed at establishing the motor adjustments necessary to restructure the phonation pattern through the use of specific exercises.[18] Semi-occluded vocal tract exercises (SOVTEs) are beneficial to the voice by improving interaction between source and filter, increasing vocal intensity, and promoting overall better vocal performance.[19] According to several studies, these exercises favor pneumo-phono articulatory coordination, increase mucosal wave mobilization of the vocal folds, reduce phonatory effort, alter the vertical position of the larynx in the neck, provide a better glottic coaptation and better resonant voice with more vocal stability and richer harmonic components.[15,20–28]

No previous studies were found that addressed possible changes in the voice pattern of the hearing impaired with CI after vocal rehabilitation. The hypothesis is that a vocal therapeutic intervention, using targeted and specific voice techniques, is necessary to optimize and improve voice production and speech sounds of the hearing impaired with prelingual deafness, even after the restoration of auditory feedback obtained by CI. This study looked at prelingual hearing impaired adults implanted at a later age, as voice and speech disorders of this population are more pronounced. According to the literature, hearing impaired children implanted at an early age present with satisfactory voice quality and acoustic analysis over time through longitudinal re-assessments, very similar to normal hearing children.[10,13,29–32] The general objective of this study is to verify if changes occur in perceptual and acoustic vocal parameters in adults with prelingual hearing loss following a specific voice rehabilitation protocol.

METHODS

The present study is a prospective and pre–post repeated measures design. This project was approved by the Ethics Committee of the institution under the protocol number 796.438.

Participants were adults with prelingual hearing impairment (hearing impairment prior to language development) who received CIs in the Cochlear Implant group of the Otorhinolaryngology Division of the Hospital das Clínicas, Medical School, USP (HC-FMUSP).

The subjects' ages were between 17 and 48 years. Inclusion criteria were as follows: Severe to profound and/or profound bilateral sensorineural hearing loss; made use of oral communication; had a literacy level adequate for the collection of speech samples; presented with a normal laryngeal examination; after CI, their auditory thresholds were 40 dB HL or better for all speech frequencies on sound field audiometry. Patients with laryngeal or lip/palate abnormalities, a history of laryngeal surgery or prior tracheotomy and those who did not complete the entire voice therapy protocol, were excluded from the study.

Twenty individuals implanted in adulthood met the inclusion and exclusion criteria and agreed to participate in the study. This was a convenience sample, considering that there were 30 prelingual deaf patients implanted in the adulthood at our CI group. From that population, only 20 agreed to participate. Subjects were randomly distributed (according to the possibility of participation in vocal therapy) into two groups with 10 patients each, five males and five females, respectively: GROUP 1 (treatment group): implanted hearing impaired with vocal therapy; GROUP 2 (control group): implanted hearing impaired without vocal therapy. Both groups had similar mean ages and time of hearing loss (in months) before the CI, as well as the number of implanted electrodes and CI adjustments (Table 1). The median time of implant use was 65.5 months (9–136) for group 1 (treatment group) and 34 months (8–171) for group 2 (control group).

All patients from both groups underwent voice-recording sessions in the Voice Laboratory of the Otorhinolaryngology Clinic of HC-FMUSP. The vocal records were performed in an acoustically treated room, and we used a desktop computer (Hewlett-Packard, Palo Alto, California, United States), the Audacity Software (v. 2.0.5 – General Public License), the Edirol UA-101 interface (Roland, Swansea, UK) and a unidirectional/condensed headset microphone (model 520; AKG, Hofgeismar, Germany) positioned between 3 and 5 cm from the individual's mouth at a 45-degree angle. Before recording the voices, the microphone was calibrated.

For Group 1 (treatment group), the voices were recorded in two periods: before and after 12 weeks of vocal therapy.

TABLE 1.
Sample Characterization: Group 1 (Treatment) and Group 2 (Control)

	Group 1		Group 2		
	Average	S.D.	Average	S.D.	*P*
Age	29.4	5.8	28.3	10.6	0.39
Hearing deprivation	280.5	97.2	280.7	143.5	0.47
Electrodes	17.8	4.8	17	4.8	0.35
Speed	901.3	367.5	1.088.7	411.4	0.18
Min. Freq.	167.8	50.5	148.2	55.4	0.22
Max. Freq.	8112.8	267.9	8111.7	380.7	0.49

Age in years, deprivation – time in months, electrodes – number of electrodes activated, speed – speed of CI stimulation, Min. Freq. – minimum frequency, Max. Freq. – maximum frequency / frequency ranges covered by CI stimulation, S.D. – standard deviation, *P* calculated by *t* test.

For Group 2 (control group), the voices were also recorded at two moments, 12 weeks apart. The speech samples used for voice recording were as follows:

1. Sustained vowel /a/: three samples were requested. Participants were instructed to phonate in their habitual pitch.
2. Reading six sentences from the Consensus Auditory-Perceptual Evaluation of Voice (CAPE-V) protocol[33] as adapted to the Brazilian Portuguese language,[34] namely, "Érica tomou suco de pera e amora," "Sonia sabe sambar sozinha," "Olha lá o avião azul," "Agora é hora de acabar," "Minha mãe namorou um anjo," and "Papai trouxe pipoca quente."

Group 1 (treatment group) subjects participated in a 12-session voice therapy protocol. Patients were only included when they attended the complete protocol. This protocol was developed to focus the training of the voice parameters and Voice Onset Time production of the plosives of the Portuguese Brazilian language. In this manuscript, only the aspects of the voice production training are described, seeking to develop better vocal adjustments and quality. We based the 12-week intervention protocol on the time needed for learning new motor control of the speech and voice production.[35] Clinically, there are protocols that propose 6–8 sessions in some cases.[24,36–38]

Therapy sessions were performed individually by the same therapist, each with a 45-minute duration. The general objectives of the proposed voice therapy program were to enhance their self-perception of their own voice production, loudness control, and pitch control; to improve pneumo-phono articulatory coordination during voice and speech production; to improve overall voice production; to reduce vocal strain, when present; and to adjust the resonance and maximize the articulation pattern aiming at increasing vocal projection. The voice therapy protocol strategies involving SOVTEs were used.[20–28,38] Progressive hierarchy of the execution duration (in minutes) and difficulty was applied. The vocal techniques used during each of the 12 voice therapy sessions were respiratory training; unvoiced fricative [s] or [ʃ]; voiced fricative [z] or [v]; sustaining air sucking exercise for 5 seconds to lower the larynx (similar to sucking spaghetti); prolonged [b]; learning to vary the melody: training on the vowel [u] with melodic variation, gliding in pitch from low to high and returning low; wider 'drinking straw' phonation in modal pitch on the vowel [u] and melodic variation; lip or tongue trills (according to what is easier for the patient to perform) in modal tone and with melodic variation; phonation on the vowel [u] in modal pitch and melodic variation using a flexible tube with water; nasal sound [m] in modal tone and with melodic variation; automatic speech task training using months of the year and days of the week; narrow straw phonation on the vowel [u] in modal tone and melodic variation; nasal sound [m] with vowels "feeling" the nasal vibration; nasal sound [m] with words that begin with this phoneme; reading tasks using projection and comfortable voice; and applying all abovementioned techniques in spontaneous speech. The voice exercises were taught and practiced in therapy and the patients were instructed to perform them daily at home, twice a day, for better results.

Voice analysis: auditory-perceptual and acoustic

The voice recordings in this study were submitted to the judgment of three voice experts (raters) on auditory-perceptual assessment using the CAPE-V protocol with scoring from 0 to 100 mm.[33,34] Prior to performing the voice analysis, raters were trained on the use of the protocol to increase their familiarity with it. For voice analysis, the phonation tasks recorded by both groups of participants were randomized onto one single CD. Male and female voices were separated on the CD to facilitate voice analysis. During the CD editing, 10% of the speech samples were randomly repeated (some patients' recordings were presented twice, with different track numbers) to verify intra-rater reliability. The following vocal parameters were classified by means of the CAPE-V protocol: overall severity, roughness, breathiness, strain, pitch, loudness, and up to two additional vocal quality characteristics.

During the CAPE-V assessment, judges were asked to classify resonance as follows: hypernasal, hyponasal, cul-de-sac, laryngeal−pharyngeal, or balanced. Moreover, in order to come up with a score for resonance, we included a classification of the resonance asking the judges to give a score of the degree of resonant alteration in each patient at both recording times on a 100 mm line (visual-analog scale, at the end of CAPE-V protocol). Acoustic analysis was carried out with the *Praat* Software package which was used to extract the *f*⍰. *Praat* (version 5.0.47 − www.praat.org) was also used to analyze the mean f_o and its variability (vf_o) during sustained vowel /a/ tests; the first and last seconds of the recordings were excluded, and the middle section of the voice production was analyzed.

Statistical analysis

Data collected were stored and analyzed using the *IBM Statistical Package for Social Sciences* (*SPSS*) software, version 05-2017 for Mac OS. The distributions of auditory-perceptual data and acoustic measurements were tested for normality using the Kolmogorov−Smirnov test. Since the data were not normally distributed, non-parametric tests were used. The results of the auditory-perceptual parameters of the CAPE-V protocol and the sustained vowel /a/ were compared, between the first and second recording for both groups (Group 1 and Group 2), using the non-parametric Wilcoxon signed rank test for related samples. The Chi-square test was used for the analysis of the resonance classification by the three judges during the first and second recording for both groups (Group 1 and Group 2). Finally, the analysis of the difference in f_o variability between the two groups was performed using the Mann−Whitney *U* test of independent samples. The results with a value of less than 0.05 were considered statistically significant. The method proposed by Bland and Altman[39,40] was used for the assessment of intra-rater agreement when evaluating the same test of auditory-perceptual parameters at different points in time.

RESULTS

The CAPE-V results of group 1 (treatment group) and group 2 (control group) are shown in Table 2. Significant score reductions were observed for the overall severity and instability parameters in group 1 (treatment group) post voice exercises. According to the classification of overall severity[41] Group 1 (treatment group) subjects presented with a moderate voice deviation (57.0 mm) pretherapy (moment 1), and with a reduction in value (48.0 mm) post-therapy (moment 2). Significant changes were also observed in Group 1's vocal instability parameters in relation to moments 1 and 2 (Table 2). In relation to Group 2, the overall severity parameters of the voice, as well as vocal instability, were similar when comparing the two evaluation moments (Table 2), with no significant differences.

No significant changes were observed in the other vocal parameters evaluated, such as H (roughness), B (breathiness), S (Strain), P (pitch), and L (loudness), for both groups between the two evaluation moments (Table 2). In terms of resonance, the judges agreed on the following classification: hypernasality, hyponasality, and *cul de sac*. Both groups did not show differences in the resonance classification

TABLE 2.
Groups 1 (Treatment) and 2 (Control) Medians and 25−75th Score Medium from the Three Judges Visual-Analog Scale (in mm) of Each Vocal Parameter of the CAPE-V's Auditory-Perceptual Evaluation

	Group 1			Group 2		
	M1 Median (p25−75)	M2 Median (p25−75)	*P*	M1 Median (p25−75)	M2 Median (p25−75)	*P*
O	57.0 (42.6−71.1)	48.0 (39.3−64.3)	0.00*	47.8 (27.1−70.8)	47.7 (32.6−71.5)	0.65
R	11.8 (1.8−19.3)	8.7 (0.5−13.4)	0.36	10.5 (7.1−25.7)	12.3 (7.9−19.9)	0.96
B	3.5 (2.1−5.0)	2.5 (0.0−5.0)	0.16	8.0 (5.3−13.4)	8.0 (4.7−19.5)	0.96
S	17.8 (9.5−28.9)	13.5 (8.9−23.7)	0.15	6.0 (3.3−17.6)	3.2 (0.0−16.8)	0.48
P	13.0 (6.8−36.4)	8.3 (2.5−18.0)	0.17	7.0 (0.0−21.6)	4.7 (2.8−7.6)	0.33
L	9.0 (4.0−16.1)	9.7 (3.5−17.5)	0.86	3.3 (2.0−11.9)	6.5 (0.0−14.6)	0.83
I	38.0 (24.9−43.6)	27.5 (15.9−34.2)	0.02*	36.0 (23.7−49.5)	37.1 (21.1−44.1)	0.83

* *P* values less than 0.05 were considered statistically significant.
Abbreviations: O, overall severity; R, roughness; B, breathiness; S, strain; P, pitch; L, loudness; I, instability; Moment 1, first sample; Moment 2, second sample.

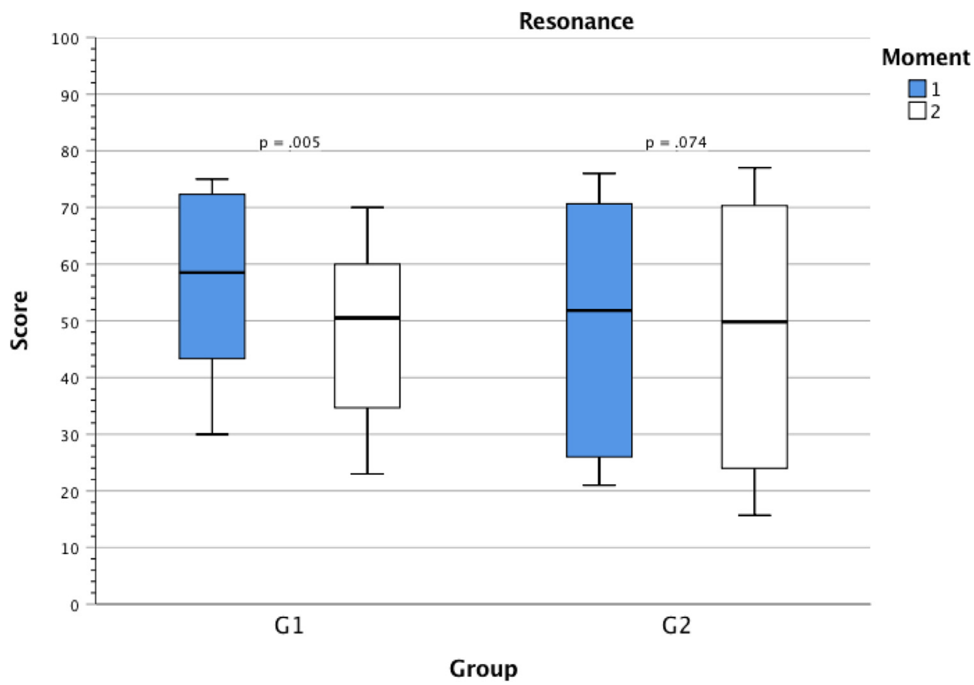

FIGURE 1. Groups 1 (treatment) and 2 (control) resonance changes score results from the visual-analog scale (in mm) at moments 1 and 2 of the voice recording.

between the two moments. However, there was a reduction in the degree of resonance alteration score between moments 1 (pre – 58.5 mm) and 2 (post – 50.5 mm) with a statistical difference (Figure 1).

The intra-rater reliability results, when comparing 10% repetition of the auditory-perceptual voice evaluations, showed consistency between the judges' analyses with a standard deviation of 4.6 mm between evaluations of the same recordings, with no significant difference (Figure 2). Because of this good agreement, we valued the opinion of the three raters in determining the average of the scores.

During the acoustic analysis of the sustained vowel /a/ obtained through the CAPE-V protocol, both groups were separated by sex due to the fundamental frequency values. A slight increase in fundamental frequency (Table 3) in moment 2 was observed in the male values of Group 1, albeit with no statistical significance. The opposite occurred

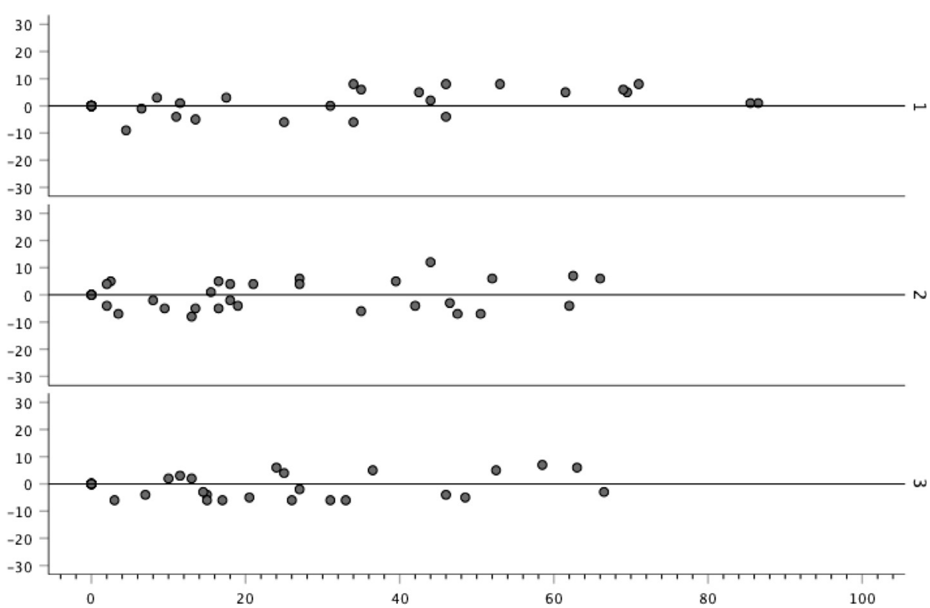

FIGURE 2. Difference at the three judges visual-analog scale (in mm) of each vocal parameter of the CAPE-V's auditory-perceptual evaluation, when comparing 10% repetition.

TABLE 3.
Group 1 (Treatment) Medians and the 25–75th Percentile Score of the Fundamental Frequency and Frequency Variation from Male and Female Acoustic Analysis at Moments 1 and 2

	Group 1					
	Male			Female		
	M1 Median (p25–75)	M2 Median (p25–75)	*P*	M1 Median (p25–75)	M2 Median (p25–75)	*P*
F0 /a/	125.3 (110.0–154.5)	134.3 (115.6–161.8)	0.50	286.0 (199.0–400.5)	235.0 (211.7–313.7)	0.35
vF0 /a/	18.0 (13.2–21.0)	14.0 (10.7–16.8)	0.08	46.7 (34.0–158.7)	23.3 (19.5–52.0)	0.52

Abbreviations: F0 /a/, fundamental frequency during sustained vowel /a/ emission; vF0 /a/, fundamental frequency variability during sustained vowel /a/ emission; Moment 1, first sample; Moment 2, second sample.

with the female values during moments 1 and 2, where there was a considerable reduction of the same. Despite these positive results, no significant differences were observed. Tables 3 and 4 display that there was no significant difference in the variability of f_o in both groups. Nevertheless, a decrease of 23 Hz was observed in Group 1 in females between the two moments (Table 3). For Group 2's f_o results, for both male and female subjects, an increase of values was observed at moment 2 in relation to moment 1 of the voice recordings, albeit with no significant differences (Table 4).

DISCUSSION

The judges of this study noted a change in the overall voice severity between moment 1 (pretherapy) and moment 2 (posttherapy). The results also showed a reduction in the degree of voice deviation from moderate (moment 1) to mild–moderate (moment 2), based on the proposed classification of voice deviation by the visual-analog scale.[41] In this study, the auditory-perceptual evaluation results (Table 2) showed that the hearing-impaired participants in both groups had higher scores in relation to the overall severity and the vocal instability indexes. The overall severity parameter relates to the voice's source and filter. The speaker's voice quality represents the joint action of the larynx and vocal tract modifying the exhaled air.[42] The proposed therapy program for Group 1 (treatment group) addressed vocal exercises with structured therapy sessions and aimed to establish motor adjustments necessary to restructure the phonation pattern.[18] SOVTEs were used to balance the energy between source and filter. SOVTEs are beneficial for the voice because they increase the interaction between source and filter and their efficiency.[19,22,28]

The presence of vocal instability in our results, especially during the sustained vowel production (sustained vowel /a/), can be justified by the discoordination of intrinsic and extrinsic laryngeal muscles and disturbed contraction and relaxation of antagonistic muscles. Lack of proper auditory feedback in hearing-impaired

TABLE 4.
Group 2 (Control) Medians and the 25–75th Percentile Score of the Fundamental Frequency and Frequency Variation from Male and Female Acoustic Analysis at Moments 1 and 2

	Group 2					
	Male			Female		
	M1 Median (p25–75)	M2 Median (p25–75)	*P*	M1 Median (p25–75)	M2 Median (p25–75)	*P*
F0 /a/	127.0 (116.5–190.7)	146.0 (123.5–187.7)	0.69	218.0 (202.8–330.2)	239.4 (197.7–266.5)	0.35
vF0 /a/	25.7 (14.0–100.5)	29.4 (13.4–96.7)	0.04*	66.0 (42.5–110.0)	66.4 (43.2–128.7)	0.69

* *P* values less than 0.05 were considered statistically significant.
Abbreviations: F0 /a/, fundamental frequency during sustained vowel /a/ emission; vF0 /a/, fundamental frequency variability during sustained vowel /a/ emission; Moment 1, first sample; Moment 2, second sample.

subjects results in functional voice disorder. In a study with hearing impaired children, a significant reduction in vocal folds adduction velocity and abduction was observed, leading to difficulty in controlling vocal fold pressure and tension during the phonation.[16] Our results agree with the literature that said that individuals with profound hearing loss or total deafness usually present with reduced voice quality and changes in their resonance and speech.[4,8,11,12]

Hypernasality was the most noted resonant focus in our sample, and it is the most common resonance deviation found in the hearing impaired. This is possibly because of the inefficient velopharyngeal control derived from lack of auditory feedback during phonation.[15,43] This additional air leak also causes the respiratory load to decrease rapidly, causing more pauses for inhalation recharge during the speech process. Another finding among children of 5−10 years indicates that the aerodynamic parameters of voice of hearing aid users differ significantly in terms of vital capacity and maximum sustained phonation.[16] The proposed voice therapy protocol for the implanted patients in this research used exercises that favored the coordination of breathing and the maximization of subglottic pressure and airflow direction, in order to obtain a better voice projection. As such, abdominal breathing exercises were used, together with prolonged voiceless and voiced fricatives as well as other SOVTEs in our protocol, favoring a better pneumo-phono articulatory coordination and quality voice.[20−28,38] Research on the physiopathology of voice and speech in hearing-impaired individuals proves that a physiological deficiency of the larynx affects phonation and articulation. Voice and speech rehabilitation should begin as soon as possible, helping to maintain correct functioning of the larynx.[44]

In addition to incomplete velum closure, we believe that, due to the lack of auditory feedback prior to the CI, the hearing-impaired individual uses the nasal structures more prominently, as a synesthetic track for better vocal perception and control and better segment production of speech. The opposite may also occur with a hyponasal resonance focus, in which the vocal tract structures are not being properly used during sound production, with probable energy reduction in the supraglottic structures and in the region of the entire face. The vocal exercise protocol included exercises that favored the expansion of the vocal tract and, consequently, improved and balanced resonance. Some of the proposed exercises, such as laryngeal lowering with air suction (“spaghetti”) and prolonged /b/, lip or tongue trills, exercises with phonation in a flexible tube with water and straws of different dimensions, and nasal sounds, all had this purpose.[15,21,25−28] Phonation exercises in tubes and narrow straws showed that, during and after the production, the velum closes, the larynx lowers, and the hypopharyngeal region enlarges.[27] We observed, in our results, that there was a reduction in the degree of resonance alteration score between the two evaluations which suggested that, although twelve sessions were not successful in altering the resonance focus, it was possible to identify a decrease in the degree of the alteration.

In regard to the fundamental frequency results, the increase of f_o in the male subjects may have occurred due to some presence of basal sound or vocal fry during the sustained vowel /a/ task in the recording of moment 1, which may have decreased the median values of the f_o at that moment. In addition, after the voice therapy, subjects could have improved the coordination of intrinsic muscles. Regardless, both values obtained from the f_o of the male patients of Group 1 (treatment group), in the two moments of recording, were higher than the average established in previous studies with the Brazilian adult population.[45−47] In regard to the f_o results in the female subjects in Group 1 (treatment group), a reduction in their value (Table 3) was observed, but without statistical significance. However, the value of f_o obtained at moment 2 (post voice therapy) was still higher compared to the average established by previous studies for the sex and age of the Brazilian population.[45−47] The f_o values obtained in our study for the late implanted subjects with congenital profound hearing loss indicated that these values are high in relation to normal hearing subjects.[9,48] Adult individuals with prelingual hearing loss may present an increased f_o due to an absent acoustic feedback and laryngeal hyperfunction.[12]

Analyzing the results of the variability of f_o, there were positive reductions, especially in Group 1 (treatment group) female subjects once trained with the vocal exercises during the 12 sessions of therapy. All SOVTEs performed in our protocol were used for providing more stable voices, improvement in the pneumo-phono-articulatory coordination and increase mucosal wave mobilization of the vocal folds.[15,24,37,38,49] In this study's treatment protocol, the time of execution of the proposed voice exercises was controlled in minutes, especially when improvement was observed in the patients. The execution time of the exercises should gradually increase to favor muscular, functional, and metabolic adaptations of the vocal folds, respecting the patient's biological individuality and following the overload principle when structuring a vocal training program.[22,50] The direct implications of vocal training involve repetition of the proposed exercises, stimulating, over time, changes in the initial vocal pattern.[51]

It was also observed that vocal exercises used with melodic variation—from high to low pitch returning to low pitch—such as lip and tongue trills, phonation in a flexible tube with water and phonation in the straws with the presence of ascending and descending glissando, were the most difficult vocal tasks to perform by participants in the therapy protocol (Group 1). In these types of exercises, it is necessary to lengthen and shorten the vocal folds with an increase in subglottic pressure. Stretching places the muscular structure in a stretched position in order to increase the range of motion and allowing greater voice flexibility.[25] This feature is, in general, important in training the suprasegmental aspects of speech, such as prosody and overall voice flexibility, and the hearing impaired with profound hearing loss have important alterations in these aspects.[4,5]

Due to these functional changes in the voice production in individuals with severe hearing impairment and the process of phonation, the authors believe that it is very important to include targeted voice therapy in their routine, aiming at restoring auditory feedback and a better auditory perception of speech sounds. We believe that the therapeutic work of voice and speech with the hearing impaired should be multifactorial, encompassing respiration, pneumo-phono articulatory coordination, phonation, resonance and articulation, as addressed in our therapeutic protocol. Research on the physiopathology of voice and speech in hearing-impaired proves that a physiological deficiency of the larynx affects phonation and articulation. Specialists, therefore, emphasize that voice and speech rehabilitation should begin as soon as possible, helping to maintain correct functioning of the larynx.[44] Despite some positive results were possible with the vocal therapy in this study, we believe that only 12 sessions of therapy with patients in Group 1 (treatment group) were insufficient with the individuals who implanted in the adulthood and have worse vocal and speech alterations. Individuals with prelingual hearing impairment have had no auditory experience and an immature neuromuscular phonatory control.[5–7]

However, working with the suprasegmental aspects of speech is also important and should be considered: prosody, speech velocity, pauses and emphases; and training of altered phonemes in addition to promoting a better intelligibility of speech, which is usually reduced in the hearing impaired. It was not possible to directly target these aspects in our protocol. We suggest additional new research with continuation of this voice therapy protocol, with more sessions and more time of vocal therapy, as well as working with the suprasegmental aspects of speech, training of production altered phonemes and an increased sample size.

CONCLUSIONS

- The implanted prelingual hearing impaired adult subjects (treatment group) demonstrated improvement in the overall voice level, reduction of vocal instability, and in the degree of resonance.
- There were no changes in the acoustic parameters in the implanted prelingual hearing-impaired adult subjects (treatment group).

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