Original Article

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Acoustic and auditory-perceptual parameters of the voice of hearing device users

Parâmetros acústicos e perceptivoauditivos da voz de usuários de dispositivos auditivos

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ABSTRACT

Purpose: To analyze and compare the voice parameters of users of two types of hearing devices (CI and HA) with prelingual and postlingual hearing loss, and verify the influence these hearing devices have on the auditory feedback and voice quality. **Methods:** The sample comprised 10 CI-using adults and eight HA-using adults – nine with prelingual and nine with postlingual hearing loss. The auditory-perceptual assessment was conducted with the Consensus Auditory-Perceptual Evaluation of Voice protocol, as well as acoustic analysis of the voice, with the PRAAT software. The statistical analysis used nonparametric tests, such as the Mann-Whitney U and the Spearman correlation, with a $p \leq 0.05$ significance level. **Results:** A difference was observed in the sociodemographic characteristics between the groups. Despite the similar results in the voice findings, a significance was observed when comparing the CI and HA groups, regarding the frequencies of the first three formants of some vowels and voice strain. The subjects with prelingual hearing loss had a higher general degree of deviation in the voice and hypernasality. **Conclusion:** There was a similarity in the voice parameters of both groups. Hence, it was not possible to infer the impact of the different types of hearing devices analyzed in the acoustic parameters of the voice.

Keywords: Hearing loss; Voice quality; Cochlear implant; Hearing aids; Speech acoustics

RESUMO

Objetivo: Analisar e comparar os parâmetros vocais de usuários de dois tipos de dispositivos auditivos, IC e AASI, com perda auditiva pré e pós-lingual, a fim de verificar a influência desses dispositivos auditivos no feedback auditivo e na qualidade vocal. **Métodos:** participaram dez adultos usuários de IC e oito adultos usuários de AASI, sendo nove com perda auditiva pré-lingual e nove com pós-lingual. Realizou-se avaliação perceptivoauditiva por meio do protocolo Consenso da Avaliação Perceptivoauditiva da Voz e análise acústica da voz pelo software PRAAT. A análise estatística utilizou testes não paramétricos, como Mann Whitney U e correlação de Spearman, com nível de significância de $p<0,05$. **Resultados:** Observou-se diferença nas características sociodemográficas entre os grupos. Apesar de resultados semelhantes nos achados vocais, observou-se significância ao comparar os grupos de IC e AASI, em relação às frequências dos três primeiros formantes de algumas vogais e tensão vocal. Os sujeitos com perda auditiva pré-lingual apresentaram maior grau geral de desvio vocal e hipernasalidade. **Conclusão:** Houve semelhança nos parâmetros vocais de ambos os grupos, não sendo possível inferir o impacto dos diferentes tipos de dispositivos auditivos analisados nos parâmetros acústicos da voz.

Palavras-chave: Perda auditiva; Qualidade da voz; Implante coclear; Auxiliares de audição; Acústica da fala

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INTRODUCTION

A person's speech and voice depend on individual factors, many of which are derived from or related to physical and/or health characteristics. Hearing loss (HL), for instance, is identified as one of the factors responsible for a series of adaptations that define some vocal markers, considered typical of the voice of a person with such a loss. Some examples of these markers are the reduced maximum phonation time, voice breaks due to pneumophonic incoordination or vocal strain, high and/or widely variable fundamental frequency, increased pitch and loudness, and imprecise articulation. Thus, these markers immediately identify the person as such, through their speech, resulting in social and psychological impacts in their lives[1,2].

Therefore, aiming to rehabilitate people with HL, improve their acquisition of oral language and inclusion in the verbal community, various hearing devices have been developed, such as the hearing aid (HA) and the cochlear implant (CI). The HA is an external amplification device that habilitates or rehabilitates the person with mild to severe HL. As for people with bilateral severe to profound sensorineural HL, the acoustic gain provided by the HA may be limited, restricted to detecting only high-intensity sounds. As an alternative, the CI is an implantable electronic device that sends electric stimuli to the auditory nerve, enabling the person to receive sound stimuli and comprehend speech[3].

The person with HL has impaired auditory feedback – i.e., a lessened or absent auditory perception of the sound stimuli produced by their own voice when speaking, due to HL. Since the absence of auditory feedback has an impact on vocal control, a person lacking it creates inadequate voice production patterns and has difficulties in the reestablishment or improvement of their voice quality, and even in the voice rehabilitation process[4].

Studies have described that auditory feedback deprivation influences the control of fundamental frequency and precision of speech articulation, in addition to acoustic parameters – such as shimmer (sound wave amplitude variation), jitter (wave frequency variation), harmonics-to-noise ratio, and formants – when compared with the standards established for normal hearing people[4-6].

Some studies conducted with this specific population, in addition to the abovementioned findings, also inferred that there is a correlation between the auditory detection data and the capacity to maintain speech frequency, demonstrating that the hearing device, responsible for promoting the rehabilitation of the auditory threshold, has a strong relationship with voice quality[4-6].

There are scarce reports of research analyzing the voice of people with HL and their auditory rehabilitation devices and investigating how the use of hearing devices might impact voice quality. Also, they are inconclusive regarding the evolution of the therapeutic process[7].

Given the above, this research aimed to contribute to the scientific community and speech-language-hearing therapeutics regarding the voice rehabilitation of people with HL that use hearing technologies, and its actual impact on the voice quality of those who have evidently improved their hearing but still have imprecise voice quality.

The objective of this study was to analyze and compare the voice parameters of users of two types of hearing devices, examining the possible influence of the CI and HA on the auditory feedback and the potential impact on voice quality. Moreover, it aimed to verify whether these technologies have an impact on voice quality when distinguishing people with prelingual HL from those with postlingual HL.

METHODS

This is a cross-sectional, observational, quantitative-qualitative study, approved by the Human Research Ethics Committee of the Universidade Federal de Santa Catarina, Under evaluation report number 2.054.587 and CAAE 65513617.4.0000.0121. All the subjects in the research signed the informed consent form, agreeing to participate.

Subjects

The nonprobabilistic, convenience sample comprised 10 CI users, eight exclusive HA users, and two normal hearing subjects (for reference recording), totaling 20 participants. Of these, 15 were females and five males, aged 18 to 45 years, including the two reference subjects (one male and one female). Among the subjects with HL of both study groups, nine had prelingual HL and nine, postlingual HL.

Firstly, the subjects were presented as CI group and HA group, aiming to differentiate them particularly concerning the type of device they used. At a second moment, all the subjects were divided into two groups according to the time of HL onset (whether it was prelingual or postlingual), to analyze the influence these aspects have on voice quality, regardless of the device they used.

Data related to age, time of HL, and three-frequency mean of auditory threshold (using the frequencies of 0.5 kHz, 1 kHz, and 2 kHz, obtained with free-field audiometry), which characterized the subjects in both study groups, are described in Table 1.

The data regarding the time of use of the device, HL etiology, and time of HL onset in the HA and CI groups, respectively, distributed by subject, are shown in Tables 2 and 3.

The inclusion criteria were established as CI-using adult subjects, attending the reference service where the research was developed, and HA-using adults in initial assessment with a multidisciplinary team (otorhinolaryngologists, speech-language-hearing therapists, psychologists, and social workers) to join a CI surgery waiting list. Moreover, the subjects in both groups had to be 18 to 45 years old, respecting the time limits of maximum vocal efficiency[8]. The subjects in the CI group had to be using the device for at least 12 months, encompassing its activation period, as well as the beginning of the rehabilitation and stabilization of the electric auditory thresholds. As for the subjects in the HA group, they had to have bilateral severe to profound HL and have used the device for at least six months.

Subjects with a history of neurologic diseases, reading and/or comprehension difficulties to understand the instructions given during collection were excluded from both study groups. Also, specifically in the HA group, those who attended the multidisciplinary assessment not having used the device in question for at least six months were excluded.

Two normal hearing subjects were selected as a reference for comparisons in the study, after having met the inclusion and exclusion criteria.

Table 1. Sociodemographic data regarding age (in years), time of hearing loss (in years), and three-frequency mean of auditory threshold (dB) of the hearing aid (n = 8) and cochlear implant groups (n = 10)

	HA			p-value	CI		
	M	SD	MED		M	SD	MED
Age	32.2	8.14	36	0.799	32.8	9.04	35
Time of hearing loss	25.7	7.18	26.5	0.293	23.4	9.6	22
Auditory threshold three-frequency* mean	50	13.3	50	0.012	25.66	3.6	25

Mann-Whitney U test p-value; *Mean with the thresholds of 0.5 kHz, 1 kHz, and 2 kHz

Subtitle: HA = hearing aid; CI = cochlear implant; M = Mean; SD = standard deviation; MED = Median

Table 2. Sociodemographic data distributed per subject of the hearing aid group, with the time of use of the hearing device, etiology of hearing loss, and classification of time of hearing loss onset

Subjects	Age	Sex	Ear	Time of use of the hearing device (in months) R/L	Etiology of hearing loss	Time of hearing loss onset
1	41	F	L/R	60/60	Genetical	Postlingual
2	28	M	L/R	12/12	Unknown	Postlingual
3	29	F	L/R	348/12	Congenital	Prelingual
4	30	F	L/R	240/240	Unknown	Postlingual
5	31	F	L	144/0	Meningitis	Prelingual
6	32	F	L/R	36/36	Unknown	Postlingual
7	33	F	L/R	84/336	Unknown	Postlingual
8	34	F	L/R	264/264	Maternal rubella	Prelingual

Subtitle: L = left ear; R = right ear; F = Female; M = Male

Table 3. Sociodemographic data distributed per subject of the cochlear implant group, with the time of use of the device (in years and months, respectively), etiology of hearing loss, and classification of time of hearing loss onset

Subjects	Age	Sex	Ear	Time of use of the device (in months)	Etiology of hearing loss	Time of hearing loss onset
1	38	F	R	22	Sudden hearing loss	Postlingual
2	45	F	R	26	Maternal rubella	Prelingual
3	35	M	R	30	Otosclerosis	Postlingual
4	45	F	R	18	Unknown	Postlingual
5	22	F	R	36	Unknown	Prelingual
6	23	M	R	26	Maternal rubella	Prelingual
7	20	F	R	36	Prematurity	Prelingual
8	29	F	L	46	Maternal rubella	Prelingual
9	35	M	L	65	Maternal rubella	Prelingual
10	36	F	R	33	Unknown	Postlingual

Subtitle: L = left ear; R = right ear; F = Female; M = Male

In this case, the normal hearing subjects had to be originally from the region where the research was conducted, for regionalism not to interfere with the voice assessment. Also, they had to be 18 to 45 years old, equally respecting the time limits of maximum vocal efficiency[8], and not present voice changes. The exclusion criteria adopted for the control subjects were the same as those for the study group.

Procedures

Initially, sociodemographic data were collected, using a questionnaire developed by the authors and consulting the medical records. Data were gathered on their current age, time of HL, three-frequency mean of auditory threshold (using the frequencies of 0.5 kHz, 1 kHz, and 2 kHz, obtained with free-field audiometry), time of use of the device, HL etiology, and time of HL onset (it was considered postlingual HL when acquired after three years old). Then, as voice sample recording protocol, the Consensus Auditory-Perceptual Evaluation of Voice (CAPE-V) was administered[9], constituted by producing the sustained /a/ vowel and sentences standardized in the instrument, in addition to a sample of spontaneous speech. The recordings were made in an acoustically treated booth, using a notebook and a unidirectional microphone, model Headset P2 Office 10 Bright BT, positioned approximately six centimeters away from the patient's mouth, without an interface. The recordings were captured directly by the computer with the AUDACITY® software, version 2.0.3, and stored in .wav format, in sample rate of 44100 Hz and 16 bits resolution. The procedures lasted approximately 15 minutes.

The analyses of the speech signals were performed using the PRAAT software[10], version 6.1.10. The short-term voice parameters were analyzed – such as the fundamental frequency (f0), shimmer (sh), and jitter (jit), harmonic-to-noise ratio (HNR), frequencies of the first three formants (F1, F2, and F3) of the /a/, /i/, and /u/ vowels –, as well as long-term measures –

such as the spectral slope, maximum intensity, and maximum frequency; the latter based on one-minute spontaneous speech samples. The long-term measures were analyzed considering that the voice is a product of the source-filter interaction and that these measures can better reflect the everyday use of the vocal tract when speaking[11].

The f0 was taken from the /a/ vowel in usual speech tone, from a stable sustained emission, with the analysis of approximately 30 cycles (mean and standard deviation). The measure was confirmed with the analysis of the sound waveform, the pulse marks by the automated extractor, and the posterior tracing of a spectral using Fast Fourier Transform (FFT), of a stationary point of the same wave. After confirming the f0, shimmer (sh), jitter (jit), and harmonics-to-noise ratio (HNR), measures were obtained using the automated extractor.

The acoustic measures of the formant frequencies of three oral Portuguese vowels (/a/, /i/, /u/) were obtained with the analysis of semi-spontaneous emissions of standard phrases contained in the Brazilian Portuguese version of the CAPE-V protocol. The vowels selected and marked for analysis were the stressed ones in the sentences: "Sônia sAbe sambar sozInha" and "Érica tomou sUco de pera e amora". As in the analysis of the fundamental frequency, the marked vowel was analyzed based on the sound waveform, the generation of a broad-band spectrogram, and the selection of a stationary point, for the measures to be generated by the automated extractor. The measures were also confirmed with the analysis of the FFT spectral tracing of the same point, and the posterior analysis of the respective spectral peaks.

The auditory-perceptual analysis of the voice was conducted according to the abovementioned protocol, classifying the voice quality in general degree of deviation, roughness, breathiness, strain, pitch, loudness, and hypernasal resonance – added by the authors – with a visual analog scale, represented by a 100-millimeter ruler, in which zero (0) corresponded to the absence of deviation, and 100, to the maximum degree of deviation. Nasality was graded as a parameter to complement the CAPE-V, due to its frequent presence in subjects with HL. Each sample was assessed only once, results being based on the first impression caused by the voice on the assessor. The resonance options offered to the assessor were: balanced, laryngopharyngeal, oral, posterior, hypernasal, and hyponasal. However, after the assessment, it was observed that all the subjects had their resonance focus classified as hypernasal. Hence, the assessor was asked to grade this focus on a 100-mm visual analog scale, as a complementary parameter of the protocol.

The auditory-perceptual analysis was conducted by a single speech-language-hearing judge, specialized in voice, with 20 years' experience in vocal analyses. The voices were delivered to the assessor in .wav format, randomized, and with no identification of the subjects.

Due to the absence of normal distribution of the data, as observed from histograms and the Shapiro-Wilk test, the statistical analysis used nonparametric tests, namely the Mann-Whitney U test and the Spearman correlation test; p-values < 0.05 were considered significant. Furthermore, the data related to the formant frequencies produced by the subjects in the study groups were compared with the data of the reference subjects and descriptively analyzed. As for the correlation values, the interpretation was based on the following R-values: from 0.20 to 0.39, a weak correlation, from 0.40 to 0.69, a moderate correlation, and from 0.70 to 0.89, considered a strong correlation.

RESULTS

The sample comprised four male and 14 female subjects, divided into two groups (HA group and CI group), besides two reference subjects (a woman and a man), totaling 18 subjects in the study group and two subjects in the reference group.

It was observed that the medians of age (p = 0.799) and time of HL of both groups were similar (p = 0.293); there was a difference only in the medians of the auditory thresholds (p = 0.012). The HA group had a median auditory threshold of 50 dBHL, whereas in the CI group it was of 25 dBHL (Table 1).

Regarding the sex, a predominance of female subjects in the CI group was verified. As for the ear, there was a predominance of implantation on the right, while in the HA group the subjects used the device on both ears. There was a contrast in the time of use of the hearing device between the groups; the mean in the CI groups was of two years, and in the HA group, 12 years (on the left ear) and 10 years (on the right ear). Regarding the HL etiologies, there were different causes between the groups; the CI group had more subjects diagnosed with maternal rubella, while the HA group had more subjects with an unknown diagnosis. In the CI group, four subjects acquired HL in the postlingual period, and six, in the prelingual period; in the HA group, three subjects had prelingual HL, and five, postlingual HL (Tables 2 and 3).

The values of the fundamental frequency (f0), jitter, shimmer, and HNR had no statistically significant differences between the groups, as observed in Table 4.

Nevertheless, it was noted that, in absolute values, the HA and CI groups were similar in most of the investigated parameters. Also, when compared with the reference subjects, there were no statistically significant differences regarding these data.

Regarding the frequency of the F1, F2, and F3 formants of the /a/, /i/, and /u/ vowels, extracted from the sentences in the CAPE-V protocol, it was verified that the means between the HA and CI groups were mostly similar – there was a statistically significant difference between the two groups only for F1 of the /u/ vowel (p = 0.013). Concerning the formant frequencies of the vowels analyzed in the speech of the reference subjects, a great similarity was observed between their absolute numbers and those of the study group (Table 5).

When correlating the acoustic analysis data – such as shimmer, jitter, harmonics-to-noise ratio (HNR), and fundamental frequency, all of them extracted from the subjects' sustained emission –, it was observed that the values found were mostly similar between the CI and HA groups. However, the jitter tended to have a moderate inverse correlation with the HNR (p = 0.051 and r= -0.466) – i.e., there was a tendency to higher HNR with lower jitter values. Also, there was a moderate direct correlation (p = 0.032 and r= -0.518) between F2/i/ and F1/a/ and a moderate inverse correlation (p = 0.027 and r= -0.521) between F2/a/ and F2 /u/. This demonstrates articulatory differentiation between the vowels emitted by the subjects in the study.

In the auditory-perceptual assessment of the voice, no differences were observed between the CI and HA groups. Nonetheless, when analyzing the differences between the subjects according to the time of HL onset (pre- or postlingual), a statistically significant difference was verified between the prelingual period (with a higher general degree of deviation) and nasality, as observed in Figure 1. The pitch and loudness parameters did not present a deviation in the auditory-perceptual

Table 4. Comparison of the pure-tone means, by sex, of the fundamental frequency values (Hz), fundamental frequency standard deviation (Hz), jitter (%), shimmer (%), and harmonics-to-noise ratio (%), with their respective p-values, between the hearing aid (n = 8) and cochlear implant groups (n = 10), and male (n = 1) and female references (n = 1), obtained from the speech emissions with the Consensus Auditory-Perceptual Evaluation of Voice protocol

	HA	CI	p-value	Male HA	Female HA	Male CI	Female CI	Male reference	Female reference
f0	199.5	193.5	0.999	127.9	209.8	144.0	214.8	122.7	220.0
f0 SD	0.65	0.95	0.929	0.24	0.71	0.80	1.01	0.35	0.24
Jitter	0.48	0.44	0.505	0.65	0.45	0.58	0.38	1.21	0.04
Shimmer	7.80	4.80	0.534	1.67	8.69	2.67	5.79	6.78	2.06
HNR	14.5	16.5	0.131	12.4	14.8	16.6	16.4	12.3	21.9

Mann-Whitney U test
Subtitle: f0 = fundamental frequency; f0 SD = fundamental frequency standard deviation; HNR = harmonics-to-noise ratio; CI = cochlear implant; HA = hearing aid

Table 5. Comparison of the frequency medians of the F1, F2, and F3 formants (in Hz) of the /a/, /i/, and /u/ vowels, between the hearing aid (n = 8) and cochlear implant groups (n = 10), and male (n = 1) and female references (n = 1), obtained from the speech emissions with the Consensus Auditory-Perceptual Evaluation of Voice protocol

	HA	CI	p-value	Male HA	Female HA	Male CI	Female CI	Male reference	Female reference
F1/a/	847.09	813.33	0.534	961.04	830.81	786.92	824.65	705.95	868.10
F2/a/	1629.79	1545.50	0.248	1007.3	1718.72	1420.00	1599.29	1273.61	1691.96
F3/a/	2727.39	2537.81	0.241	1985.19	2833.42	2496.68	2555.44	2621.25	3226.33
F1i//	337.31	359.76	0.722	291.82	343.81	283.85	239.29	327.90	388.70
F2/i/	2314.84	2192.84	0.594	1992.6	2360.88	2089.63	2237.07	1947.15	2358.22
F3/i/	2910.82	2792.12	0.131	3048.53	2891.15	2797.80	2789.69	2689.66	2849.09
F1/u/	314.48	396.19	0.013*	320.5	313.62	318.65	429.43	411.02	317.53
F2/u/	1202.61	1163.20	0.657	1209.97	1201.56	902.75	1274.82	2151.20	1002.66
F3/u/	2844.27	2694.56	0.424	3481.77	2753.2	2646.76	2715.04	3574.09	2792.91

Mann-Whitney U test; *p < 0.05
Subtitle: n = Number of subjects; HA = hearing aid; CI = cochlear implant

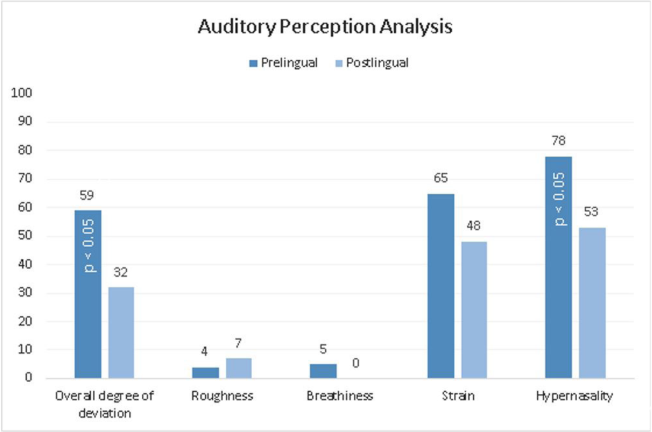

Figure 1. Description of the percentages obtained in the Consensus Auditory-Perceptual Evaluation of Voice protocol, considering the maximum of 100 mm in the visual analog scale, based on the auditory-perceptual analysis of voice quality, comparing all the subjects divided into groups of time of hearing loss onset (pre- or postlingual) (n = 18)
Mann-Whitney U test

assessment – without markings in the CAPE-V protocol, they were not included for analysis in the study.

The data from the acoustic analysis were correlated with those from the auditory-perceptual analysis, between the two groups. Again, a great similarity was observed among the findings, regarding the time of HL, acoustic gain, age of the subjects, jitter, shimmer, and fundamental frequency. However, a statistically significant difference was verified between the F1 /a/, F2 /i/, /u/, and F3 /a/, /u/ formants, when correlated with the vocal strain and the general degree of voice quality deviation – the greater the frequency of the said formants, the greater the voice change.

When analyzing the correlation of the spectral slope ($p = 0.009$; $r = 0.595$) and the maximum frequency of long-term analysis ($p = 0.012$; $r = 0.579$) with the data on the voice strain of both groups (CI and HA), statistically significant values were observed, with a moderate direct correlation, as well as in the short- and long-term values correlated between the formant frequencies and the spectral decline and the general degree of deviation, nasality, and strain ($p > 0.05$).

DISCUSSION

It is essential to reflect on the various forms of auditory rehabilitation and the great advances in the algorithms of the hearing devices when related to factors such as time of HL, acoustic gain, and voice parameters, to understand how these devices impact and benefit the users' communication and, consequently, voice quality. A study verified the shortage of research on the voice quality of subjects with HL and highlighted that, when they exist, they do not precisely demonstrate the effects of CI on the improvement of the users' voice quality. In these cases, interventions other than the hearing device alone are necessary, such as auditory rehabilitation and voice therapy[12].

The CI users that participated in this study had a lower auditory threshold mean in the frequencies of 0.5, 1, and 2 kHz when compared with the HA group, agreeing with studies that demonstrated that the technology of the CI to reestablish the auditory threshold is superior when compared with the HA[3].

Regarding the type of device, it was observed that the HA group stood out with its longtime use, in relation to the CI group. The reason for this may be due to the concession for HA, which was established in Santa Catarina long before that of the CI, based on the regulatory law no. 1,278, of October 20, 1999[13]. Also, a great variety of HL etiologies was observed in the subjects of this study, although with a predominance of idiopathic and/or gestational period causes. These factors may be associated with the low-frequency of diagnostic tests, such as genetic mapping, as various genes involved in the auditory system can be changed[14].

Concerning the acoustic parameters of voice assessed in this study, extracted from the sustained emission, the values of the fundamental frequency (f0), jitter, shimmer, and HNR were greatly similar between the groups. However, studies demonstrate that subjects with HL that used devices such as CI or HA presented changes in these parameters when compared with normal hearing subjects[4,15-19]. Moreover, a study verified reduced f0 values in subjects with HL after the CI surgery when compared with the preoperative group[2]. It is further highlighted that the study population in the CI group had more subjects with prelingual HL, a factor that may have influenced the values found in the acoustic analysis. The comparisons with the reference subjects were made only for the descriptive analysis, as the main objective was to compare the users of two different devices. Therefore, no control group was used.

The comparison of the CI and HA groups called attention for the absence of statistical differences regarding the voice parameters analyzed, based on the speech tasks extracted from the CAPE-V protocol. This factor has a strong relationship with the heterogeneity of the sample and its aspects, such as sex, time of auditory deprivation, time of hearing loss onset, time of use of the hearing device, etiology of the hearing loss, among others, as such information has proved to directly influence the person's voice quality, and each one has a specific behavior depending on the hearing device used.

In the analysis of the first three formants (F1, F2, and F3) of the /a/, /i/, and /u/ vowels, extracted from the CAPE-V protocol, a higher frequency of F1 /u/ was observed in the CI group when compared with the HA group. This indicated that, in these subjects, the position of the tongue when producing the vowel in question was anteriorized, increasing the space in the pharyngeal cavity. A study observed that the F1 of the /a/ vowel was changed in the HA users when compared with the CI users. This suggests that the device may indirectly improve the capacity to maintain the format of the vocal tract, especially the position of the tongue[20]. This finding agrees with those in the present research; however, it should be highlighted that the said study performed the comparison in children.

Also, regarding the formants, since the F2 is determined by the size of the oral cavity, from its decrease it is inferred that the tongue was more anteriorized when articulating the vowels, in both study groups. Indeed, data demonstrate that people with HL commonly have a changed F2 when compared with subjects with normal hearing, indicating the anteriorization of the tongue during speech[21].

However, in the present research, the F2 frequency of the /i/ vowel had an inverse correlation with the F2 frequency of the /u/ vowel in both groups ($p = 0.027$). That is, the higher the F2 value of the /i/ vowel, the lower the F2 frequency of the /u/ vowel, indicating that, in both groups, the subjects performed enough articulatory movements to distinguish the phonetics between the vowels. This is an extremely important factor in the intelligibility of speech, as these vowels have very different articulatory points one from the other[22], especially regarding the rounding of the lips and positioning of the tongue when speaking.

Concerning the age of the subjects of both groups, a direct correlation ($p = 0.033$) was observed with the F2 of the /a/ vowel, extracted from the speech tasks in the CAPE-V protocol. Hence, the older the person, the higher the F2 /a/ frequency, possibly related to the decrease in muscle tone, which s characteristic of advancing age. This possible decrease could cause the tongue to spread and, consequently, diminish the space in the oral cavity. Nonetheless, it is highlighted that this hypothesis was not tested in the present research because muscle strength assessments were not performed. Even so, a study that analyzed the effects of age on the production of formants demonstrated changes in the formant frequencies, especially F2, relating age to the decrease in the participants' tongue muscle tone[23].

Regarding the time of HL onset, it was observed that in the CI group there were more subjects with prelingual HL, whereas, in the HA group, the predominance was of subjects with postlingual HL. However, even with such a difference, the absolute values obtained in the auditory-perceptual analysis of the voice were similar, demonstrating that this information does not influence the voice sample of both groups. Although these were the results obtained in the present research, it is known that adults with prelingual HL, who were implanted late, when already an adult, can have important changes in their voice quality and speech production[15]. Thus, it is suggested that further studies be conducted to confirm this datum.

When dividing the subjects into groups according to the time of HL onset, significant values were observed, with $p < 0.05$, regarding the F2 /a/ and F3 /u/ formants, both related to the postlingual HL group. It can be inferred that those in this group had their tongue anteriorized when producing the /a/ vowel and had a higher laryngeal elevation when producing the /u/ vowel[17]. Thus, it is important to reflect on each subject's type of HL, as subjects with prelingual HL sometimes have more changes in their voice quality. This is due to the longer time without auditory feedback, whereas those with postlingual HL had had some auditory experience and sometimes an established oral language, consequently leading to a better performance in speech and better voice quality[11].

Concerning the auditory-perceptual analysis of the voice, no statistically significant differences were noted between the CI and HA groups in terms of the parameters assessed. The data found show great similarity in relation to the groups, and what seemed to strongly influence these findings was the time of HL onset (prelingual or postlingual), as the subjects with prelingual HL had late cochlear implantation. Also, even the postlingual HL group acquired it in their early childhood (six years old) and did not necessarily demonstrate the influence of the device, as there were few subjects in each study group.

When comparing the voice parameters of both groups regarding the time of HL onset, little difference was observed specifically between roughness, breathiness, and strain. However, in the prelingual group, exceptionally higher values were observed for the general degree of deviation and strain, reinforcing findings that indicated that these subjects have in general worse voice quality than groups with postlingual HL[21].

Furthermore, the higher degree of nasality and strain was notorious in the group with prelingual HL, a factor that can be associated with the incorrect velopharyngeal coordination during vocal production. It is further believed that the degree of nasality may have interfered with the overall impression on the voice quality, as nasality is an aspect commonly cited as a distinctive marker of the voice of people with HL[1,2,15,16] and that the subjects with a higher degree of nasality were those who, in this study, had a higher general degree of deviation in voice quality. This finding is possibly related to the difference in time of auditory deprivation and absence of feedback in both groups, as various studies present this factor as a great influence on the voice quality of the person with HL[4,18,24].

When the findings on short- and long-term acoustic analysis were compared with the data on the auditory-perceptual analysis of the groups, a correlation was observed of the formant frequencies and spectral decline with the general degree of deviation, nasality, and strain. The F1, F2, and F3 frequencies correlate with strain in voice quality. This datum may be related to the tongue movements, which can result in the perception of strain in the person's voice production, as well as an association with lip, pharyngeal, and palatal constriction, which may also be related to strain and/or hypernasality. Hence, since the data show a change in the structures of the vocal tract of the person with HL when producing speech, this condition reflects a worse perception of voice quality, resulting in the "characteristic" voice of the person with HL, making it so peculiar to the listener[21].

The spectral slope measure is the difference in energy between frequency bands in a larger speech sample. Its result refers not only to the glottal wave but also the final product of the interaction between the source and the filter. This was assessed in the study group because of the notorious association of the subjects with HL with strained voice[25]. In this case, no significant difference was observed between the spectral decline values in the CI and HA groups. However, in absolute values, the HA group had an apparently steeper slope, which may indicate a laryngeal hypofunction. It is suggested that further studies be conducted to investigate the spectral slope of the speech of subjects with prelingual and postlingual HL, considering the findings previously exposed in the present study, regarding voice quality.

Based on the results of this study, it is essential to reflect on the importance of the voice rehabilitation process in the subjects with HL, since it was made clear that the absence of adequate auditory feedback resulting from the HL leads to changed voice production patterns. As a consequence, these have an impact on the effectiveness of oral communication and quality of life.

Moreover, the findings of the present study can provide knowledge to aid professionals in their rehabilitation clinical practice. Specific information, such as the values obtained both in the acoustic analysis of the voice and auditory-perceptual analysis can provide directional data for more efficient therapeutics.

A difficulty was perceived in this study regarding the recruitment and adherence of subjects, as a large portion of the population came from places far away from where the data was collected. Moreover, not all the voice parameters were assessed in this study, which can be seen as a limitation of the research. Another limitation was related to the fact that the auditory-perceptual analysis of the voice was made by only one assessor. Although the voice samples were not submitted to a judging committee, the analysis was made by a specialized assessor, with a broad experience in this type of assessment. Hence, it is suggested that future studies encompass a larger and more homogeneous total sample regarding aspects such as time of deafness, sex, and other sociodemographic data, as these factors can influence the analyses.

CONCLUSION

There was a great similarity in the voice parameters of both groups. Hence, it was not possible to infer the impact of the types of hearing devices analyzed regarding their interference with the quality of the acoustic parameters of the voice resulting from the reestablished auditory feedback. Nevertheless, the time of HL onset proved to influence the voice quality, as the subjects with postlingual HL had a voice quality with less hypernasality and less general grade of deviation. Both the HA and the CI groups had a frequent strain in their voice quality, caused by adaptations in the structures and organs of the vocal tract.

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