FREQUENCY COMPRESSION ON SPEECH RECOGNITION IN ELDERLY PEOPLE WITH POSSIBLE COCHLEAR DEAD REGIONS

Compressão de frequências no reconhecimento de fala de idosos com possíveis zonas mortas na cóclea

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ABSTRACT

Purpose: to evaluate and compare the performance of elderly people with and without cochlear dead regions in speech recognition tests, in silence and in noise, using hearing aids with and without the activation of the nonlinear frequency compression algorithm. **Methods:** 38 elderly people with mild to moderate hearing loss and descending configuration, distributed based on the results of the white noise masking technique, in: Group A – 24 elderly people without evidence of cochlear dead regions; Group B – 14 elderly people with evidence of cochlear dead regions. The Lists of Sentences in Portuguese test was applied, seeking the Percentage Index of Sentence Recognition in Silence and in noise. The measurements were obtained using the hearing aids without and with nonlinear frequency compression. **Results:** both Group A and Group B showed statistically significant improvement in silence with the hearing aids with the algorithm; in noise no group presented significant difference without and with frequency compression. Comparing the groups, there was no significant difference in silence without and with frequency compression. In noise without the algorithm there was significant difference, Group B being the better of the two. In noise without frequency compression there was no significant difference. **Conclusion:** in silence, both groups presented significant improvement in performance using hearing aids with frequency compression. In noise, there was no difference between the results without or with frequency compression. Comparing the groups, the measurement obtained in noise with hearing aids without the algorithm was the only one that presented significant difference, in which the group with cochlear dead regions presented better performance.

KEYWORDS: Hearing Aids; Hearing Loss, High-Frequency ; Aged; Speech Discrimination Tests; Speech Perception

INTRODUCTION

Considering that the cochlear tonotopic organization is arranged so that the high frequencies are identified in the basal region of the cochlea and the low ones in apex[1], it is natural and frequent that the sensorineural hearing loss first affect the cells responsible for detecting high frequencies, characterized by a downward sloping in the audiogram. Subjects with this audiometric configuration usually have their recognition of speech clearly hindered, since the transmission of acoustic energy of consonant sounds, related to higher frequencies and fundamental to speech recognition[2], is impaired.

In some cases, hearing loss stems not only from a decrease in functional activity of inner hair cells and/or adjacent neurons of the cochlea, but from the non functionality of these structures that leads to disruption of transmission of information generated on the basilar membrane to the Central Nervous System. Regions with these characteristics are

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called dead regions in the cochlea (ZMC)[3] and when they are present they end up further promote a gap in the recognition of the subjects' speech.

Under these conditions, the detection of sound with frequency corresponding to the ZMC can only occur if sufficiently intense to generate a vibration in the basilar membrane that spreads to regions neighboring to it, where the hair cells remain functional. Thus, in subjects with ZMC it is possible that a tonotopic reorganization occurs[4], which can not be restricted to the cochlear level, also leading to cortical plasticity. In this sense, research indicates that a lesion at the base of the cochlea, causing ZMC at high frequencies, can make the cortical area corresponding to the ZMC to adjust to respond to that frequency adjacent which will be responsible for its detection[5,6].

Considering the percent of subjects with ZMC[7-9], many of whom have low acceptance rates for the use of hearing aids[7,10], the authors emphasize that caution is needed in the amplification of high frequencies in subjects with thresholds higher than 55 dB NA[11,12], since the excessive amplification of sounds that can not be detected by their corresponding auditory fibers may distort the acoustic information. In cases of possible ZMC, the suggestion is that the amplification be promoted only for frequencies located up to 1.5 to 2 times above that identified with ZMC, otherwise the speech recognition of the subjects could be harmed[12,13].

The limitations in the amplification of the high frequencies and the suggestion that, because of neuroplasticity, subjects with ZMC would make more effective use of low frequencies information in speech recognition[5,6], makes one think that the hearing aids that are able to move the high frequency acoustic information to be perceived by low frequencies bring greater benefit to the communication from these subjects.

In this context are the hearing aids with nonlinear frequency compression algorithm (CNLF), a technology developed after several other methods of lowering the frequency, that ended up causing considerable distortion of the speech signal. By allowing the choice of a cutoff frequency (FC), from which the CNLF begins to act, this technology allows the preservation of natural formants of low frequencies, which are not affected by the compression, while maintaining the fundamental frequency of the human voice and causing less distortion of sounds[14,15].

The benefit provided by CNLF in patients with ZMC is not yet clear. Studies with technologies that follow the same principle of CNLF, such as transposition of frequency and compression of frequency of fricative sounds, show conflicting results. There is an improvement of identification of fricatives, decrease of frequent errors and increased acoustic information transmitted to the patient[16-19], or else no improvement in speech recognition is observed[16-20].

For all of the above, in order to establish the best practices in settings of hearing aids for subjects with ZMC, this study aims to assess and compare the performance of the elderly with and without ZMC in speech recognition tests in silence and in noise, using hearing aids with and without activation of the nonlinear frequency compression algorithm.

METHODS

This research has a quantitative character, of the descriptive observational and cross-sectional type. It took place in the Laboratory of Hearing Aids (LPA) of the institution of origin, registered in the Projects Office with number 032630 and approved by the Ethics Committee in Research of the institution with the certificate number 05765712.3.0000.5346. All study participants received a full explanation of the nature, purpose and procedures and signed an Informed Consent (TCLE) document.

A survey of personal and audiological data from medical records of 275 subjects who came to the Center of Selection and Adaptation of Hearing Aids (NUSEAPA) to initiate the process of selection and fitting of hearing aids from August 2012 to January 2013 was conducted.

Upon analysis of the records, were considered as criteria for inclusion in the sample: ages between 19 and 60 years or above 60 years old, considered adults and seniors, respectively, by the classification of the World Health Organization[21]; having a hearing loss from mild to moderate[22] and downward sloping[23] acquired in the post-lingual period; show a Percentage Index of Speech Recognition (IPRF) without hearing aids of at least 60 % and having never used hearing aids.

Based on these criteria, 55 subjects, being six adults, aged 19 and 60, and 49 elderly over 60 years of age were contacted by telephone to participate and schedule a consultation for the assessments. Data collection occurred from October 2012 to March 2013.

The adults have gone through all the procedures for conducting the research, but due to the small number of subjects in this age group, in order to have a sample homogeneity and considering the particularities currently highlighted in the fitting of hearing aids in the elderly, it was chosen to include in the final study only subjects older than 60 years.

The subjects were submitted to the Mini Mental State Examination (MMSE), in order to detect possible cognitive changes that could influence the results of examinations[24]. The choice of such an examination is justified because it is considered a screening instrument of cognitive function that is fast and easy and no special equipment is needed. In addition to providing information on different cognitive parameters, it is one of the few tests validated and adapted for the Brazilian population.

In addition, all passed through medical history and visual inspection of the external auditory canal. Also, subjects that had sensorineural hearing loss with thresholds higher than 90 dB NA at high frequencies and/or hearing loss strain with a threshold difference greater than 50 dB per octave, criteria established as indications of possible ZMC[25], were assessed to identify ZMC through the masking technique with white noise[10].

After this phase, the procedures were initiated with the use of hearing aids, which consisted in checking the adjustments of the hearing aids by means of measurements with a microphone probe and applying the Lists of Sentences in Portuguese (LSP) test[26].

Considering the claim that ears with and without ZMC show different responses to speech tests[6], since the LSP was performed binaurally, it was chosen to exclude the sample of elderly subjects who had evidence of ZMC in just one ear. Thus were excluded from the study subjects aged below 60 years, with a history of neurological disorder, cognitive and/or articulation factors interfering in assessment, excess of earwax or other changes in the external auditory canal observed during visual inspection of the auditory canal and evidence of the presence of ZMC in just one ear.

Following the criteria set, and after the identification of subjects with potential ZMC, they were divided into two groups as follows:

- Group A: 24 subjects without evidence of ZMC, aged 61 to 83 years, being seven females and 17 males;
- Group B: 14 subjects with evidence of ZMC, aged 69 to 84 years, being five females and nine males.

As stated in the inclusion criteria, all subjects showed downward sloping hearing loss (Figure 1).

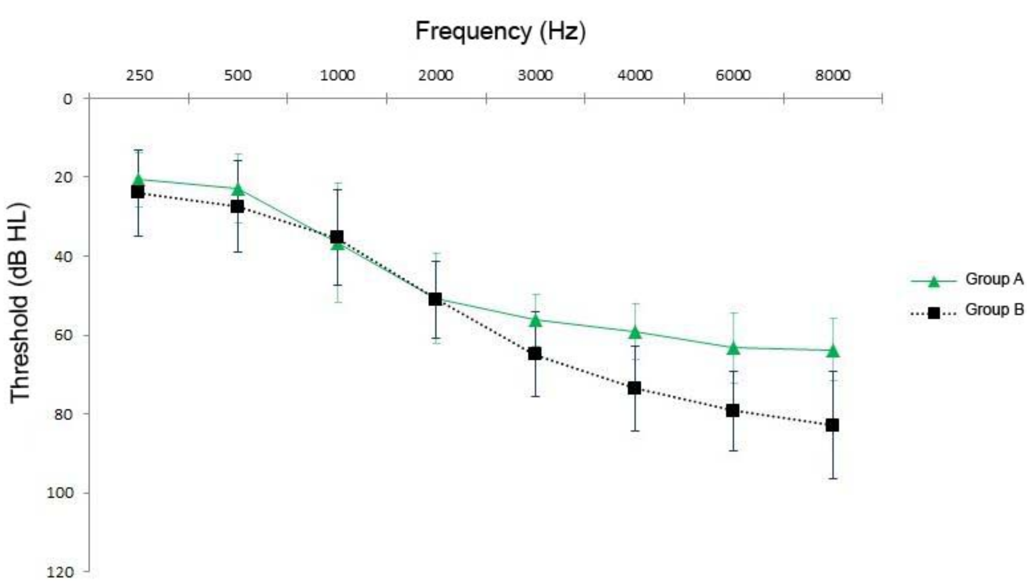

Figure 1 – Mean and standard deviation of tone thresholds of the better ear of the subjects in group A and group B

Below are describe the procedures for classifying groups with the identification of dead regions in the cochlea through the masking technique with white noise, the scheduling of hearing aids and data collection with the application of the LSP test.

Classification of subjects in the groups: identification of the dead regions in the cochlea using the masking technique with white noise

This technique[10] showed very strong agreement with the above criteria indicative of possible ZMC[25] and showed that white noise has an effect similar to the threshold equalizing noise (TEN)[27], which is internationally recognized as a simple and efficient method for identifying possible ZMC. Therefore, the masking test by white noise is considered as a reliable alternative for identifying the possible presence of ZMC.

The measurements were performed in a soundproof booth using a digital two-channel audiometer, brand *Fonix Hearing Evaluator*, model FA 12 type I and earphones type TDH-39P, brand *Telephonics*.

The test consists of the simultaneous and ipsilateral presentation of white noise to pure tone, i.e., the two sounds were presented to the same ear, while the thresholds masked in the frequencies that presented the criteria of indication of possible ZMC were investigated. As indicated by the author of the test, to make it shorter and less tiring, it was decided to use the level of noise presentation only at 70 dB NA[10].

When the masked thresholds obtained were at least 10 dB above the absolute threshold and the masking level used, the result was considered indicative of the presence of ZMC[27].

Scheduling of hearing aids

Considering the fact that all research participants presented bilateral descending hearing loss, two hearing aids without activating the CNLF algorithm and two with the activation of this feature were scheduled for each patient. Hearing aids used were of the same brand and model and characterized by being the BTE (behind the ear) type, of digital technology with 6 setting channels, with output and maximum gain of 128 dB and 58 dB (a coupler of 2 cc), respectively. These hearing aids have activation or deactivation features of CNLF and provide two parameters for setting, jointly adjusted, of this algorithm: the FC, that can be chosen from 1.5 to 6 kHz and the compression ratio (RC), which varies from 1.5:1 to 4:1.

The scheduling was done before the arrival of the subject for care by means of access to the software of the company responsible for the manufacture of the hearing aids used in the study. The NAL-NL1 prescriptive rule was used for definition of the adjustments of the hearing aids. The settings for gain and maximum output by frequency, as well as the adjustment of the FC and RC regarding the CNLF, were performed by the rapid adjustment of the software, which assumes the best possible settings for the audiological characteristics of the subject in question. Only the resource of feedback cancellation was kept, and the others algorithms were disabled. Once connected, the hearing aids were programmed to operate in a silence program and with an omnidirectional microphone. It is noteworthy that the only difference between the two pairs of hearing aids used in this study was the activation or not of CNLF.

In order to check the settings of the hearing aids and the deactivation/activation of the CNLF algorithm, measurements with probe microphone were performed before the start of testing. Moreover, in all cases, the hearing aid fitting was performed with ear molds of the simple invisible type in acrylic and the size of ventilation was determined in accordance to the audiometric configuration of each subject.

Lists of Sentences in Portuguese test (LSP)

LSP[26] consists of a list of 25 sentences, seven lists of ten sentences and noise with speech spectrum, with the sentences and the noise recorded on a CD in independent channels, allowing the presentation both in silence and in noise. The test allows to obtain the Sentences Recognition Threshold in Silence (LRSS), of the Percentile Index of Recognition of Sentences in Silence (IPRSS), of the Sentence Recognition Thresholds in Noise (LRSR) and of the Percentile Index of Recognition of Sentences in Noise (IPRSR).

The measurements were performed in the open field, in a soundproof booth, using an audiometer of the same brand and model aforementioned. The sentences were presented using a *Toshiba Digital Compact Disc Player*, model 4149, connected to the audiometer.

In order that the conditions of presentation were held constant, before starting the test was held a calibrating of the output of each channel of the audiometer VU meter, using as reference the pure tone present in the first track of the CD. For noise calibration, both the pure tone present in channel one, and the noise present in channel two, were placed at level zero.

For research of LRSS and LRSR, the application of the material was performed by the procedure called "sequential strategy, adaptive or ascending-descending"[28], which determines the Threshold for

Speech Recognition (LRF), i.e., the required level for the subject correctly identify around 50 % of the speech stimuli presented in a certain condition. Following this strategy, when the subject is able to correctly recognize the speech stimulus, its intensity is reduced; otherwise, its intensity is increased. An answer is considered correct only when the subject repeats, without error or omission, the whole sentence presented.

The presentation times of sentences recommended in the literature[28] are of 4 dB in the first sentences, until the first change in response type; later they are of 2 dB. However, the equipment used for this study did not have the possibility of time frames of 4 and 2 dB; thus, ranges from 5 and 2.5 dB respectively were used. The values of presentation of each sentence were recorded in the study protocol, and then the means were calculated based on the intensities of sentence presentation, from the first change in response type.

As the existence of a difference of 7 dB between speech and noise (speech below noise) was observed by the author of the material, the subtraction of 7 dB from the speech values recorded and observed in the equipment dial was adopted as a procedure for calculating the LRSS and LRSR.

This procedure was used for the research of the thresholds in silence and in noise. In the test with background noise, this one was kept constant at 65 dB NPS (A).

Importantly, the LRSS and LRSR were screened only for reference, to determine the intensity at which the IPRSS and IPRSR would be researched.

For obtaining IPRSS and IPRSR, the intensity of presentation of the sentences was kept fixed in the threshold found in the research of LRSS and LRSR of each subject when this one was using the hearing aids without activating the algorithm of CNLF. A list of sentences was presented in each condition and, during the testing, the subjects' answers were recorded in a protocol that allowed for the analysis of th e indexes, considering as an error only the word(s) omitted or incorrectly repeated. Thus, since each word within each list corresponds to a success percentage, totaling 100 % in each list, the results of the indexes are displayed in percentages[29].

All the measurements of the LSP test were performed with the aid of hearing aids, being researched LRSS, LRSR, IPRSS, IPRSS first with the hearing aids, without CNLF, and, afterwards, were researched IPRSS and IPRSR with hearing aids with CNLF. For greater clarity, the measures regarding those performed with the hearing aids without activating the CNLF will be followed by the letters SC (without non-linear compression of frequencies) and the ones carried out with the hearing aids with the activation of the algorithm will be represented by the letters CC (without non-linear compression of frequencies).

Initially, the subjects were assessed with the hearing aids without activating the CNLF. Before starting the actual evaluation, familiarization training to the test was conducted by means of the first five sentences of list 7B without background noise. To facilitate the recognition of the first sentence of each list, in order to ensure understanding of the test, the initial intensity of presentation of sentences in silence for training was from 10 to 20 dB above the Threshold for Speech Recognition (LRF)[30]. Below are the first ten sentences of list 1A that were used for the research of the LRSS SC. With the intensity fixed in the figure found in LRSS SC, the research of the IPRSS SC was conducted by applying list 1B.

Also using the hearing aids without activating CNLF, were obtained the measures during background noise at a constant intensity of 65 dB NPS (A). The five last sentences of list 7B were applied as training during background noise. The initial intensity of presentation of the sentences in this case was of 10 to 20 dB above the noise. After the training, list 2B was presented for research of the LRSR SC. With the intensity fixed in the figure found in LRSR SC, IPRSR SC was researched by means of list 3B.

Then, the measures were conducted, following the same parameters for assessment with the hearing aids with activation of CNLF. Training was conducted with the same sentences, both in silence and noise since, because it was a training, the repetition of the sentences would not affect the results. Therefore, after training in silence, came the research of the IPRSS CC, using list 4B. In order to maintain the same intensity of test of the condition without activating CNLF and later comparison among results, IPRSS CC was researched in the intensity found in the research of the LRSS SC. Then was carried out the training in the condition of noise and afterwards IPRSR CC was obtained by means of the presentation of list 6B. Just as in silence for obtaining IPRSR CC, the intensity was fixed in the figure found in LRSR SC.

To avoid lettering effects similar to placebo effects, blinding of the sample was performed for the hearing aids that were being evaluated at all times, i.e., the subjects did not know whether they were being evaluated with hearing aids with or without activation of CNLF, although the examiner knew that information.

Data analysis

The data were descriptively analyzed and statistically treated by using the program *Statistica* version

9.0. In order to verify the normality of the variables, test *Shapiro-Wilk* was applied.

Two types of analyzes were performed: comparison between groups A and B, separately and among themselves under conditions CC and SC. To analyze the groups separately, the paired t test for two dependent samples or Wilcoxon were used, according to the normalcy presented by the variable. As for the analysis between groups, t test was used for independent variables.

The statistical significance level of $p < 0.05$ (5 %) was considered and the results showed significance highlighted by an asterisk (*). To enrich the discussion of the study, significance levels of $0.5 < p < 0.1$ (10 %) were treated as statistical trend, having been highlighted by two asterisks (**).

RESULTS

Table 1 shows the descriptive measures and comparative tests of IPRSS and IPRSR of subjects in group A using hearing aids SC and CC.

Table 1 – Distribution of subjects in group A (without ZMC) regarding the results of the percentage rate of speech recognition in silence and in noise using hearing aids with and without compression of frequencies

	GROUP A (n = 24)			
	Min	**Max**	**Average**	***p value***
IPRSS SC	35,52	95,46	61,24	**0,079****
IPRSS CC	37,12	100	65,44	
IPRSR SC	3,57	90,09	55,99	0,230
IPRSR CC	7,77	92,15	56,29	

Paired t test for two dependent samples (IPRSS), Wilcoxon test (IPRSR); (**) value with a statistically significant trend (0.05 < p < 0.1).
Caption: IPRSS – Percentile Index of Recognition of Sentences in Silence; IPRSR – Percentile Index of Recognition of Sentences in Noise; SC – without non-linear compression of frequencies; CC – with non-linear compression of frequencies.

Group A (without ZMC) showed a statistical trend of difference in performance between the IPRSS obtained using hearing aids SC and CC. However, there was no statistically significant difference between the use of hearing aids SC and CC in the task of speech recognition in noise.

Table 2 shows the descriptive measures and comparative tests of IPRSS and IPRSR of subjects in group B using hearing aids SC and CC.

Table 2 – Distribution of subjects in group B (with ZMC) and the results of the percentage rate of speech recognition in silence and in noise using hearing aids with and without compression of frequencies

	GROUP B (n = 14)			***p value***
	Min	**Max**	**Average**	
IPRSS SC	29,97	81,00	55,27	**0,097****
IPRSS CC	46,40	92,80	64,34	
IPRSR SC	44,46	88,92	67,12	0,936
IPRSR CC	17,76	97,68	67,48	

Paired t test for two dependent samples; (**) value with a statistically significant trend (0.05 < p < 0.1).
Caption: IPRSS – Percentile Index of Recognition of Sentences in Silence; IPRSR – Percentile Index of Recognition of Sentences in Noise; SC – without non-linear compression of frequencies; CC – with non-linear compression of frequencies.

Group B (with ZMC) showed a statistical trend of difference in performance between the IPRSS obtained using hearing aids SC and CC. However, there was no statistically significant difference between the use of hearing aids SC and CC in the task of speech recognition in noise.

Figures 2 and 3 present the IPRSS and IPRSR of each subject of groups A and B, using hearing aids SC and CC.

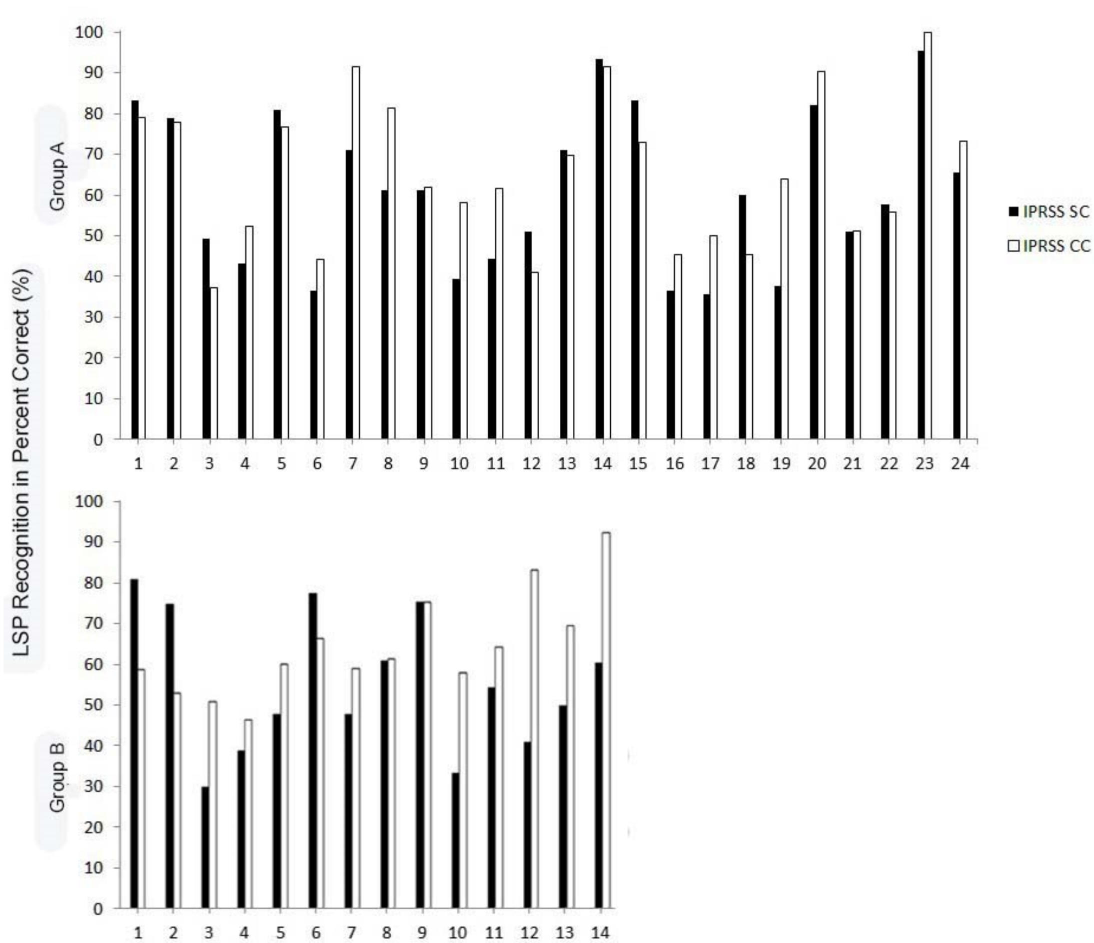

Figure 2 – Comparison among the percent ratio of recognition of sentences in silence of each individual, of groups A and B, using hearing aids with and without compression of frequencies

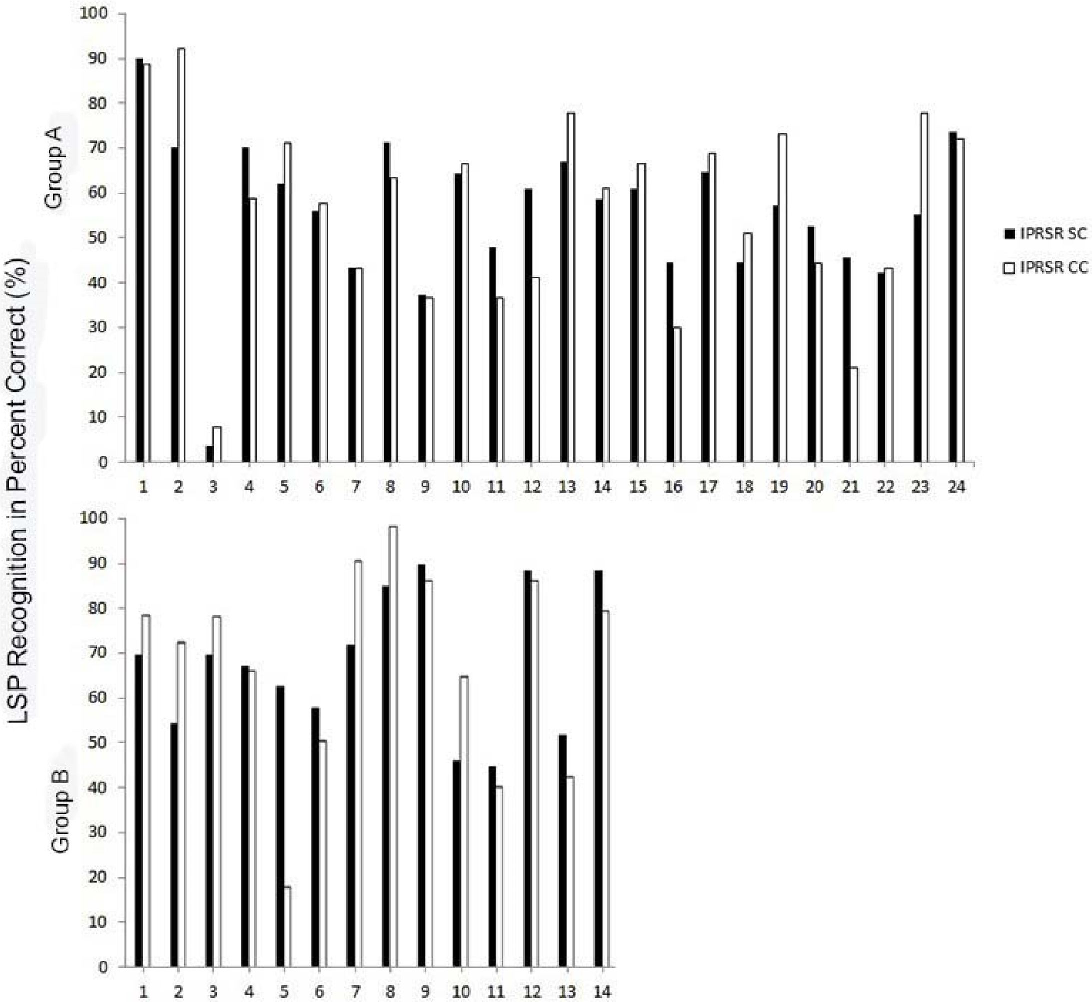

Figure 3 – Comparison among the percent ratio of recognition of sentences in noise of each individual, of groups A and B, using hearing aids with and without compression of frequencies

Table 3 shows the descriptive measures of IPRSS and IPRSR, obtained using hearing aids SC and CC of groups A and B, as well as the results of the tests comparing between the groups in each measurement.

Comparing the results of groups A (without ZMC) and B (with ZMC) in the measurements obtained by means of LSP carried using hearing aids SC and CC, it was observed that there was no statistically significant difference of performance between the groups in IPRSS SC and IPRSS CC. As for IPRSR SC, it presented a statistically significant difference between the groups, and the performance of group B (with ZMC) was better than the performance of group A (without ZMC). The results of IPRSR CC did not show a statistically significant difference between groups.

Table 3 – Comparison of subjects in groups A and B regarding the results of the percentage rate of speech recognition in silence and in noise using hearing aids with and without compression of frequencies

	GROUP A (n = 24)			GROUP B (n = 14)			*p value*
	Min	Max	Average	Min	Max	Average	
IPRSS SC	35,52	95,46	61,24	29,97	81,00	55,27	0,340
IPRSS CC	37,12	100	65,44	46,40	92,80	64,34	0,841
IPRSR SC	3,57	90,09	55,99	44,46	88,92	67,12	**0,049***
IPRSR CC	7,77	92,15	56,29	17,76	97,68	67,48	0,133

T test for independent variables; (*) statistically significant value ($p < 0.05$).
Caption: IPRSS – Percentile Index of Recognition of Sentences in Silence; IPRSR – Percentile Index of Recognition of Sentences in Noise; SC – without non-linear compression of frequencies; CC – with non-linear compression of frequencies.

DISCUSSION

It is known that in the audiologists' everyday clinical practice, tests for identification of ZMC are not part of the classical set of procedures to be performed. Still, many of these professionals look to the characteristics of the audiogram of their patients and if they show evidences of possible ZMC, such as hearing thresholds above 90 dB NA, they may affect the choice of the settings of the hearing aids to be adapted.

Therefore, in order to not simply lose the high frequency acoustic information, by the non-amplification of this region, in the case of subjects with ZMC, the use of methods of lowering the frequencies can be considered for the high frequency signal to be perceived by those with better hearing thresholds.

In this study it was noticed that in a situation of silence the CNLF showed statistical tendency to favor speech recognition in subjects with hearing loss in a downward sloping in general, regardless of whether or not they show ZMC (Tables 1 and 2). These results comply with studies conducted in subjects with and without ZMC, where audibility and recognition of monosyllables, consonants, plural and/or fricatives in silence showed better results with the use of techniques for lowering the frequencies[14,15,17,18,20]. It is also highlighted that the n of the present research was established by means of a sampling calculation, based in international articles, which, mostly have smaller samples[14,15,17,20] than the one from the study that is presented.

Regarding such results, what was found was that most audibility caused by the increase of acoustic information transmitted to the patient, due to compression of high frequencies to be perceived by low frequencies, caused the subjects without and with ZMC to have the highest percentage in the recognition of speech than those obtained with conventional amplification.

In the case of patients without ZMC, this advantage observed with the use of the algorithm may be related to a number of limitations presented by conventional hearing aids, such as the restricted width in the possible frequency band to be amplified, limitations of gain and maximum output, in addition to risk of noise or report of discomfort[15,31]. With the use of the CNLF, these points are overcome and the signals of high frequencies become audible, despite the algorithm causing the emergence of certain devices that lead to the distortion of certain sounds[17,20,32]. Still, in silence these distortions do not seem to influence the benefit provided by the algorithm.

In the case of the patients with ZMC, some authors state that the conventional amplification of high frequencies may not bring benefits or even harm its recognition of speech[7,12,13]. As this study did not take action without the use of hearing aids, it is not possible to ensure that the effects brought about by this type of amplification were beneficial or detrimental to the subjects with ZMC. In any event, by analyzing the findings, it is believed that, in most cases, both conventional amplification and amplification with CNLF have provided some degree of improvement in speech recognition of the subjects, and this one is higher with the use of the algorithm.

The results obtained are consistent with the statement that, for patients with ZMC, the amplification must be promoted preferably for frequencies located until 1.5 to 2 times above the first frequency identified with ZMC[12,13]. It is this range of frequencies that the acoustic signal shall be detected after being compressed, promoting, in silence, good results for speech recognition.

In noise (Tables 1 and 2), the results showed that there was no difference statistically significant of performance using hearing aids with and without CNLF, both in group A (without ZMC) and group B (with ZMC), which complies with the literature of the field[15,20,32,33]. In this condition, the results obtained with the use of CNLF may have been limited by the fact that the algorithm does make audible only the speech signals, but also the high frequencies noise[15]. With that it is possible to conclude that the S/R relationship promoted is not yet enough to improve the speech recognition of these subjects. Base on the results, it is believed that these effects equally impact subjects without and with ZMC.

Analyzing Figure 2, which represents the individually obtained results in silence, initially considering the subjects without ZMC, two elderlies had a similar performance using hearing aids without or with activation of the CNLF, 12 elderlies improved and ten worsened with the activation of the CNLF. The data obtained with the 14 subjects with ZMC in the same test had the same ratio of subjects (two) that showed a similar performance without or with the activation of the CNLF, nine elderlies improved and three worsened with the use of the algorithm.

It is noteworthy that an analysis of the data on the score obtained in cognitive screening, schooling and time of the hearing loss was performed, but no significant difference was found between groups.

In both groups, 50 % or more of the subjects improved their speech recognition on some level with the use of hearing aids with CNLF and no case exceeded 20 % worsening. For patients with ZMC, the extent of improvement was considerable for some subjects, with findings compatible with the idea that patients with these characteristics tend to get used to CNLF faster than the subjects without ZMC[20]. The above results and statement are explained by the fact that subjects with ZMC are already daily exposed to a lowering of the natural frequencies, since the detection of input signals with frequency corresponding to ZMC is performed by neighboring regions, whereas the group without ZMC would have to get used to the new signal processing.

Moreover, considering the fact that the improvement is already seen in half of the subjects immediately, it is believed that the percentage of seniors benefiting from the use of CNLF in this study may, after a period of acclimatization, be even greater, as already observed in previous studies[14,33,34].

In the noise situation (Figure 3), of the 24 subjects of group A (without ZMC), two showed results similar to the conventional amplification and with CNLF, 13 improved and nine worsened with the activation of the feature. Considering the subjects of group B (with ZMC), six improved and eight worsened with the use of CNLF.

The percent of subjects that showed some degree of improvement in IPRSR was kept similar to the one observed in IPRSS, about 50 %, but what was observed was that the extension of improvement was smaller than the one observed in silence, specially in group B (with ZMC), in which the subject had a significant percent of worsening.

It should be noted that, apart from the question previously commented on the increased audibility of speech signals as much as noise after using the CNLF, this study should take into consideration the fact that the sample consists exclusively of elderly. Individuals in this age group naturally have more difficulty in recognizing distorted signals and/or amid background noise signals due to changes in information auditory processing[35,36]. The findings of this study comply with the consideration outlined above, since even with the distorted signal, seniors are able to benefit from the increased acoustic information conveyed by the use of CNLF in silence, but this did not occur in noise.

Thus, the sum of the distortion of the speech signal, the background noise and greater difficulty from the elderly in recognizing the speech signal in these situations may have limited the benefit of CNLF in speech recognition in noise by the elderly in this study. Therefore, it should be taken into consideration when choosing the conventional amplification or with CNLF, which must be performed carefully.

It is noteworthy that the p value found in the analysis ($p < 0.1$) and the variability of results shown between subjects suggest the need for further studies, preferably with larger samples, so that possible inference and generalization of results may occur.

From the comparison of the results of group A with group B (Table 3), it was observed that there was no statistically significant difference between the performance of groups in the IPRSS SC condition, i.e., both groups showed similar results using hearing aids without CNLF. These results are consistent with studies that claim that conventional amplification of high frequencies can benefit subjects without and with ZMC, despite these benefits being more evident for the first group[9,37].

One of the factors that may have contributed to the positive results presented, mainly by the group of subjects with ZMC, may be related to the prescriptive rule used in this study. Taking into account the fitting of hearing aids in patients with hearing loss of sharp downward configuration, the NAL-NL1 is a rule that differs from others by prescribing minimum amplification to high frequencies[38], based on findings from studies that indicated that the excessive amplification of high frequencies does not contribute to the speech recognition of individuals with such audiometric configurations[11,12].

Thus, NAL-NL1 prescribes amplification to those frequencies that can also aid in speech recognition, that is, to the frequencies without evidence of ZMC, while not providing excessive amplification to the frequencies with possible ZMC, which could impair the speech recognition of subjects.

As for the measurements obtained in silence with subjects using hearing aids with CNLF (IPRSS CC), as both groups significantly benefited from the use of the algorithm when compared to conventional amplification, no statistically significant difference was observed between groups. In silence, it seems, in general, that the application of CNLF is not only indicated to the patients with ZMC, but can also bring benefits to subjects without ZMC[33].

Taking into account the report that subjects who do not get good results in monosyllable recognition tests with the conventional sign tend to show better performance when the stimulus is compressed[39], one might think that the fitting of hearing aids with frequency lowering algorithms should be considered an alternative to patients with sloping configuration hearing loss who did not have a satisfactory benefit with conventional amplification. Thus, the increased transmission of acoustic information promoted by the algorithm may provide greater audibility and speech recognition to these subjects, especially in silence situations.

Comparing the results of both groups in the measurements obtained while there was noise, there was a statistically significant difference in performance in IPRSR SC, i.e., the subjects in group B (with ZMC) showed better results with conventional amplification of high frequencies than group A (without ZMC).

The results of this study contradict the account of previous research indicating that the amplification of high frequencies in subjects with ZMC may provide no benefit and even impair speech recognition, especially in noisy environments[7,12,13]. Furthermore, a study found that amplification of high frequencies can assist individuals with ZMC in improving their speech recognition, if at low noise levels[37].

In any event, due to the uniqueness of the results, it was decided to verify if there were significant differences in some characteristics between the groups with and without ZMC, which could indirectly influence results in noise. Thus, besides the analysis of data regarding the score obtained in cognitive screening, schooling and time of the hearing loss, as previously mentioned, was also compared the occupation/profession of the individuals in the groups; however, as observed in the previously analyzed variables and as expected, because the patients were treated at a public hearing health facility, the occupations were similar among all subjects in the sample and were related predominantly to rural activities and odd jobs.

Considering the fact that the aspects mentioned above do not show influence on the findings of the groups, it was found that authors that have obtained similar results in other studies suggested a plausible explanation for these: reorganizing at cortical level, which would occur in subjects with ZMC at high frequencies.

One of the studies evaluated 22 adults and seniors with hearing loss, and half of them showed results indicating possible ZMC in the TEN test. The subjects were evaluated using their own hearing aids and stimuli were monosyllables, handled with low-pass filters, and the test was conducted in silence. It was observed that the subjects with ZMC obtained better results than subjects without ZMC, especially when the level of stimulus presentation was low[5].

In the current study, as well as in the aforementioned, it was also observed a better performance of the group of subjects with ZMC, although being different the fact that this time the results were observed in noise and without manipulation of the stimuli used. Another compliance among studies was that the group of subjects with ZMC obtained better results when the level of stimulus presentation was weak. Since IPRSR was researched with the fixed value in which LRSR was found, which corresponds to approximately 50 % of correct sentences, it can be said that the perception of the subject evaluated for intensity of sentence presentation was that it was relatively weak.

The survey is also consistent with another study in this direction, which evaluated 12 subjects with sensorineural hearing loss, totaling 11 ears of patients with ZMC. Tests of frequency discrimination, detection of amplitude modulation and consonant identification tests that passed through low-pass filter were applied. The results of the study showed a better performance of the ears with ZMC in the tests[6].

It is noteworthy that, in this study, both groups showed no significant difference between the hearing thresholds of 250-2000 Hz; therefore, no difference between the thresholds of these frequencies might have influenced the results.

What is suggested is that in the case of patients with ZMC, lesions in the basilar membrane would be more focused, making the rest of the cochlea assume a better function[7]. This statement is consistent with the fact that other regions of the cochlea neighboring ZMC, assume the function of detection of sounds with a frequency input corresponding to ZMC when they are sufficiently intense.

However, this cochlear reorganizing seems to reflect at cortical level. The findings that patients with ZMC seem to use the low-frequency information more effectively than subjects without ZMC may indicate that, after a certain time of auditory deprivation associated with ZMC, the brain areas that previously normally responded to high frequencies (with ZMC) are detecting and recognizing low frequencies[6]. The difference between cortical stimulation of subjects with and without ZMC is that on the former, although the cortical area corresponding to that frequency with hearing loss is less stimulated, it continues to show some activity, albeit minimal. As for the subjects with ZMC, the cortical region corresponding to ZMC is simply not stimulated, allowing the neighboring area, corresponding to the region that starts to detect that frequency at cochlear level, to "take ownership" of that cortical area.

Although the results that were favorable to patients with ZMC in this study not dealing with stimuli that were modified by low-pass filters, as in previous work, based on the studies so far developed in this field of knowledge, it is believed that the hypothesis of cortical reorganization is presented as the most plausible explanation to the findings of better performance of subjects with ZMC compared to subjects without ZMC in the IPRSR SC.

Some might question the fact that they are elderly patients; however, it must be remembered that, despite being slower in mature nervous systems, the process of neuroplasticity persists throughout life[40].

Still, since the subjects with ZMC now have greater ability to use low-frequency information, it would be expected that they presented better performance in IPRSR CC, since the main function of CNLF is precisely to make the high frequencies to be perceived by low frequencies. Nevertheless, such results have not occurred in this study.

Considering a possible explanation for these findings, it is believed that in IPRSR SC, although noise is also present, the amplification provided to the high frequencies was not enough to make audible the noise of such frequencies or at least it was not sufficient to interfere with speech recognition of subjects with ZMC. As for IPRSR CC, as mentioned previously, the noise related to the high frequencies become audible as soon as they are perceived by the low frequencies.

Some methods of transposition/compression of frequencies that identify and act solely on fricatives and/or affricates may help diminish this effect of perceived noise caused when CNLF acts unconditionally[17,18]. One of these studies in normal-hearing subjects with simulated ZMC found that this new feature promoted improvement in the identification of fricatives in syllable initial position, although tests have been performed in silence[18].

For all of the above, considering the findings of this study and the literature of the field, it is believed that it is not possible to generalize the prescription or not of the use of frequency lowering in patients without and with ZMC. It is suggested that, from the point of view of the research, further studies are performed to promote the development/improvement of these algorithms in order to minimize the negative effects of CNLF in noise, as well as to deepen the possible involved cortical changes in patients with ZMC.

For clinical practice, it is suggested that, when possible, be considered the effects of the ZMC in speech recognition of individuals so that the features and algorithms available in hearing aids be applied in the most appropriate way for each case.

CONCLUSION

In silence, the use of hearing aids with CNLF tended to provide greater benefits to speech recognition for the elderly than the use of hearing aids without activating the CNLF. This advantage of the hearing aids with CNLF was noticed for the group of elderlies without ZMC and for the group with ZMC. In the situation with noise, none of the groups showed improved performance with the use of hearing aids with CNLF and results similar to those found with conventional amplification were kept.

Comparing the results of the groups with and without ZMC in silence, the performance between them was similar when tested with hearing aids withoutCNLF. The same happened when evaluated with hearing aids with CNLF. In a noisy situation, the group of subjects with ZMC showed better results with the use of hearing aids without CNLF than the group without ZMC. As for the results in noise with the use of hearing aids with CNLF, they were similar between the groups.

RESUMO

Objetivo: avaliar e comparar o desempenho de idosos sem e com zonas mortas na cóclea em testes de reconhecimento de fala, no silêncio e no ruído, usando próteses auditivas sem e com compressão não linear de frequências. **Métodos:** participaram 38 idosos com perda auditiva de grau leve a moderado e configuração descendente, distribuídos, com base nos resultados da técnica de mascaramento com ruído branco, em: Grupo A – 24 idosos sem indícios de zonas mortas na cóclea; Grupo B – 14 idosos com possíveis zonas mortas na cóclea. Aplicou-se o teste Listas de Sentenças em Português, pesquisando-se os Índices Percentuais de Reconhecimento de Sentenças no Silêncio e no Ruído. As medidas foram obtidas com próteses auditivas, sem e com compressão de frequências. **Resultados:** o grupo A e o B apresentaram melhora significante no silêncio com as próteses auditivas com compressão de frequências; no ruído nenhum grupo apresentou diferença sem e com compressão de freqüências. Comparando-se os grupos, não houve diferença no silêncio sem e com compressão de frequências. No ruído sem a ativação da compressão houve diferença significante, sendo melhor o desempenho do grupo B. No ruído com a ativação do recurso não houve diferença significante. **Conclusão:** no silêncio, ambos os grupos apresentaram melhor desempenho usando próteses com compressão de frequências. No ruído, não houve diferença entre os resultados sem e com compressão de frequências. Comparando-se os grupos, a medida obtida no ruído com próteses auditivas sem compressão de frequências apresentou diferença, na qual o grupo com zonas mortas obteve melhor desempenho.

DESCRITORES: Auxiliares de Audição; Perda Auditiva de Alta Frequência; Idoso; Testes de Discriminação da Fala; Percepção da Fala

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