Original Article

https://doi.org/10.1590/2317-6431-2019-2282

Audiology Communication Research
ISSN 2317-6431

Hearing improvement and influence of hearing deprivation time on speech perception in cochlear implant users

Ganho auditivo e influência do tempo de privação auditiva na percepção de fala em usuários de implante coclear

Bianca Bastos Cordeiro[1], *Marcos Roberto Banhara*[2], *Carlos Maurício Cardeal Mendes*[1]

ABSTRACT

Purpose: To evaluate speech perception improvement in the absence and presence of competing noise; to evaluate, after three months using a cochlear implant, whether there was a correlation between speech perception in these two conditions, and to correlate the time of hearing deprivation and the implanted side with speech perception in the absence and presence of noise. **Methods:** Twelve individuals with severe-to-profound hearing loss who underwent cochlear implant surgery participated in this clinical trial. Speech perception was assessed using the Lists of Phrases in Portuguese test, using the Opti Omni directionality, in situations of absence and presence of competing noise. **Results:** Speech perception with the use of Opti Omni directionality in the absence and presence of competing noise increased when compared with preoperative speech perception; these findings were not associated with hearing deprivation time or implanted side. **Conclusion:** There was an improvement in speech perception both in the absence and presence of competing noise, with a strong correlation between these two situations. Besides, there was no association between time of hearing deprivation without the use of hearing aid, or the implanted side, with performance in speech perception.

Keywords: Cochlear implant; Speech discrimination tests; Sensory deprivation; Speech intelligibility; Deafness

RESUMO

Objetivo: Avaliar o ganho de percepção de fala na ausência e na presença de ruído competitivo; avaliar, após três meses de uso do implante coclear, se houve correlação entre a percepção de fala nas duas condições e correlacionar o tempo de privação auditiva e o lado implantado com a percepção de fala na ausência e na presença do ruído. **Métodos:** Participaram deste ensaio clínico 12 indivíduos com perda auditiva de severa a profunda, submetidos à cirurgia de implante coclear. A percepção de fala foi avaliada através do teste Listas de Sentenças em Português, utilizando a direcionalidade *Opti Omni*, em situações de ausência e presença de ruído competitivo. **Resultados:** A percepção de fala na ausência e na presença de ruído competitivo aumentou, em comparação com a percepção de fala pré-operatória com a utilização da direcionalidade *Opti Omni* e estes achados não tiveram associação com o tempo de privação auditiva ou o lado implantado. **Conclusão:** Houve ganho na percepção de fala, tanto na ausência, como na presença do ruído competitivo, com forte correlação entre essas duas situações. Além disso, não houve associação entre tempo de privação auditiva sem o uso do aparelho de amplificação sonora individual ou o lado implantado com o desempenho na percepção de fala.

Palavras-chave: Implante coclear; Testes de discriminação de fala; Privação sensorial; Inteligibilidade da fala; Surdez

Study carried out at Hospital Santo Antônio, Obras Sociais Irmã Dulce – OSID – Salvador (BA), Brasil.
[1]Universidade Federal da Bahia – UFBA – Salvador (BA), Brasil.
[2]Universidade do Estado da Bahia – UNEB – Salvador (BA), Brasil.
Conflict of interests: No.
Authors' contribution: BBC participated in designing the study, collecting and interpreting the data, and developing the article; MRB participated in revising the article; CMCM, as advisor, participated in analyzing and interpreting the data, and revising the article.
Funding: Coordenação de Aperfeiçoamento de Pessoal de Nível Superior – CAPES, finance code 001.
Corresponding author: Bianca Bastos Cordeiro. E-mail: biancabastosfono@gmail.com
Received: December 12, 2019; **Accepted:** March 16, 2020

INTRODUCTION

The cochlear implant (CI) is a device surgically implanted in the scala tympani of the cochlea, used along with conventional hearing aid (HA) to rehabilitate adults with severe-to-profound sensorineural hearing loss and/or poor speech perception[1].

Choosing the most adequate ear for CI implantation in postlingual adult patients poses a challenge, as there are no evidence-based recommendations[2]. The decision can lean on the patient's preference – if there is no anatomical contraindication – or the surgeon's choice – which most of the time means an arbitrary decision[3]. Some implantation centers choose to operate the worst ear (i.e., the one with the longest auditory deprivation and least auditory residue) because there may be no additional benefit in implanting it in the ear with most auditory residue – especially when using the HA is a possibility, which bilaterally stimulates the auditory pathway, besides aiding in sound localization and speech-in-noise comprehension[4]. On the other hand, studies are demonstrating that the most residual hearing there is on the adult's implanted side, better is their speech perception[5].

An often complaint from people with hearing loss is the difficulty to communicate in noisy environments. A simple reason behind such difficulty in understanding speech when surrounded by noise is the signal-to-noise ratio (SNR)[6]. However, recent studies indicate that hearing difficulties are not necessarily characterized by high noise levels; they can be perceived in positive SNR and low noise levels, as well[7]. Implanted adults' low speech perception in background noise was noted even when tested in an ideal SNR condition, as compared with actual hearing environaments[8]. Hence, to improve SNR, various techniques can be used, of which the two most common ones to improve speech-in-noise perception are the directional microphones and the adaptive noise reduction systems[9]. Oticon Medical's Neuro™ System comprises the Neuro™ Zti implant and either the Neuro™ One or Neuro™ Two speech processor, presenting an integrated microphone directionality system named Free Focus™, which uses the difference in acquisition time between the processor's two microphones to reduce input sound coming from directions other than those that are of the patient's interest. This directionality has three adjustment modes: omnidirectional (either Opti Omni or Speech Omni, chosen by the audiologist when programming it), split directionality (directional in higher frequencies and omnidirectional in lower ones, with spatial selectivity in higher frequencies) and full directionality (directional in the whole spectrum, with strong spatial selectivity, prioritizing speech intelligibility in high noise level environments)[10,11]. The automatic mode, recommended by the manufacturer as default for use with adults, is called tri-mode and combines one of the omnidirectional modes with the split and full directionalities[10,11].

Day-to-day hearing conditions vary greatly in comparison to the ideal hearing conditions, and competing environmental noise is frequent in the most different spaces CI users go to. In 72% of the daily using time, the individual is in an environment where the omnidirectional mode is used[10]. Thus, evaluating the decrease in speech perception from the absence to presence of competing noise can aid when indicating and choosing the technological resources (including microphone directionality) and CI programming that favors implanted adults' speech perception in noisy environments[12].

This study aimed to evaluate the improvement in speech perception in the absence and presence of competing noise, investigate whether there was a correlation between speech perception in one and the other condition after three months of CI use, and correlate the time of auditory deprivation and the implanted side with speech perception in the absence and presence of noise.

METHODS

This article is an integral part of a randomized crossover open-label clinical trial, whose purpose is to compare the Opti Omni and Speech Omni directionalities, used in tri-mode, in CI users' speech perception with and without competing noise. This study was developed upon approval by the Research Ethics Committee of the *Hospital Santo Antônio – Obras Sociais Irmã Dulce* (OSID), under evaluation report no. 2.949.287, CAAE Certificate 95669818.7.0000.0047. This paper was registered in the Brazilian Registry of Clinical Trials website - ReBEC, under number RBR-4pjt82. The Universal Trial Number (UTN) to identify this clinical trial is U1111-1241-9567.

The sample calculation considered the significance level of 5%, test power of 80%, a standard deviation of 0.25 for two-sequence crossover design, with a margin of superiority of 30% and a difference in proportions of 5%, resulting in a sample of 12 participants. Hence, 12 individuals with bilateral severe-to-profound postlingual sensorineural hearing loss were selected. They had been submitted to cochlear implant surgery at the *Hospital Santo Antônio* – OSID between November 2017 and January 2019. The patients' inclusion sequence and speech test are described in Figure 1.

When activating the speech processor, the tri-mode with Opti Omni directionality was the option made by the audiologist in all 12 patients. There was no need to disable any electrode in any of them throughout the research. After three months using the CI speech processor, having signed the Informed Consent Form (ICF), the Lists of Phrases in Portuguese test (LPP) was performed in both the absence and presence of competing noise.

The lists of phrases to be used in the speech test were randomly drawn. They were first presented without competing noise at 0° azimuth, one meter away from the patient's head, at the intensity of 65 dB. Then, another draw was made from another list of phrases, also presented at 0° azimuth, at the intensity of 65 dB, whereas the noise was presented at 180° azimuth,

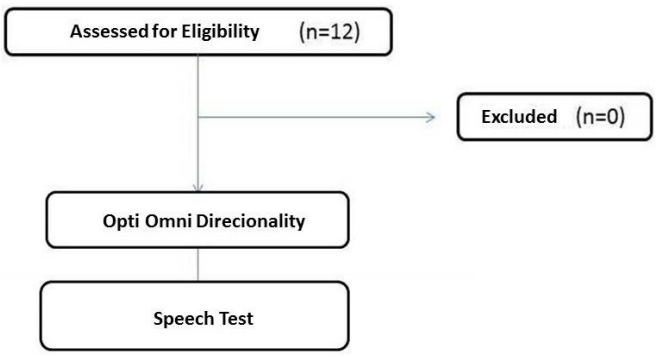

Figure 1. Inclusion of patients and application of speech test
Subtitle: n = number of patients participating in the research

at an intensity of 55 dB, setting a signal-to-noise ratio (SNR) of +10 dB. This SNR was chosen in the attempt to resemble acoustic environments closer to reality. The words correctly repeated were taken note of and then counted according to their importance for message comprehension. Thus, each function word (i.e., one that only has grammatical significance, serving as a phrase-linking element) was given one point, while each content word (i.e., one with lexical content, essential to convey the semantic information) was given two points. The added points were multiplied by the index for each phrase, as proposed by the authors of the test[13].

Speech perception with and without competing noise after three months using the speech processor was described for statistical analysis through the respective medians and interquartile intervals, given the asymmetry of the distributions measured through the asymmetry coefficient of the third moment centered on mean order r. Spearman correlation test was used to assess the degree of correlation between speech perception with and without competing noise, and between the time of deprivation and speech perception, according to the implanted side. The association between implanted side and speech perception, according to the presence or absence of competing noise, was calculated through the standardized difference in means (d), using the Wilcoxon test with a significance level of 5%. To qualify the association obtained through the value of d, Cohen's criterion was used: [0-0.2]: absent; [0.2-0.5]: small; [0.5-0.8]: moderate; > 0.8: large.

The analyses were made in the R^3 statistical package, version 3.4 for Linux Ubuntu.

RESULTS

Regarding the general characteristics of the study's 12 participants, attention is called to the equal proportion of men and women, in working age, mean age 39 years (IQI = 16.4), with a low but varying time of auditory deprivation without HA (Md = 3.5; IQI = 10) years, and varied hearing loss etiology (Table 1).

Variation in speech perception without competing noise was also noted, 1.4 times medianly greater (40% greater) than that of the same individuals exposed to competing noise after three months using CI processor with Opti Omni directionality (Table 2).

The correlogram between the speech perception in the absence and the presence of competing noise revealed, through Spearman correlation test, a high positive correlation (r = 0.86; p = 0.0003) – i.e., as speech perception in silence increases, speech perception in noise also increases, and vice-versa (Figure 2).

When evaluating the correlation between time in years of auditory deprivation (without using HA) and speech perception both in the absence and the presence of competing noise (%), in relation to the implanted side, low correlation was noted in general, indicating that the implanted side did not interfere (Table 3).

No important differences were noted between speech perception with and without competing noise in relation to the CI side (Table 4).

Table 1. General Characteristics of the individuals (n = 12)

Variables	n (%)	[Minimum-Maximum]; Md (IQI)
Gender		
Male	6 (50)	-
Female	6 (50)	-
Age (years)	-	[20.7 – 52.6]; 39 (16.4)
Time of auditory deprivation without HA (years)	-	[0 - 32]; 3.5 (10.5)
Etiology		
Unknown – progressive	5 (41.7)	-
Ototoxicity	2 (16.7)	-
Traumatic brain injury	2 (16.7)	-
Acoustic trauma	1 (8.3)	-
Mumps	1 (8.3)	-
Measles	1 (8.3)	-
Implanted ear		
Right	7 (58.3)	-
Left	5 (41.7)	-
Preoperative speech assessment		[0 – 0]; 0 (0)

Subtitle: n = number of patients participating in the research; Md = median; IQI = interquartile interval; HA = hearing aid

Table 2. Speech perception in the absence and presence of competing noise after three months

Speech perception	n	[Minimum-Maximum]; Md (IQI)
Without competing noise	12	[25.1-92.4]; 41.9 (31.2)
With competing noise	12	[16.2-77.4]; 28.3 (18.1)

Subtitle: n = number of patients participating in the research; Md = median; IQI = interquartile interval

Table 3. Correlation between deprivation time and speech perception, in relation to implanted side

Deprivation time	Speech perception without competing noise r* (p-value)	Speech perception with competing noise r* (p-value)
Left side	0.10 (0.9500)	0.40 (0.4500)
Right side	0.14 (0.7600)	0.16 (0.7300)

*r = Spearman correlation coefficient; p = result probability is due to sample randomization

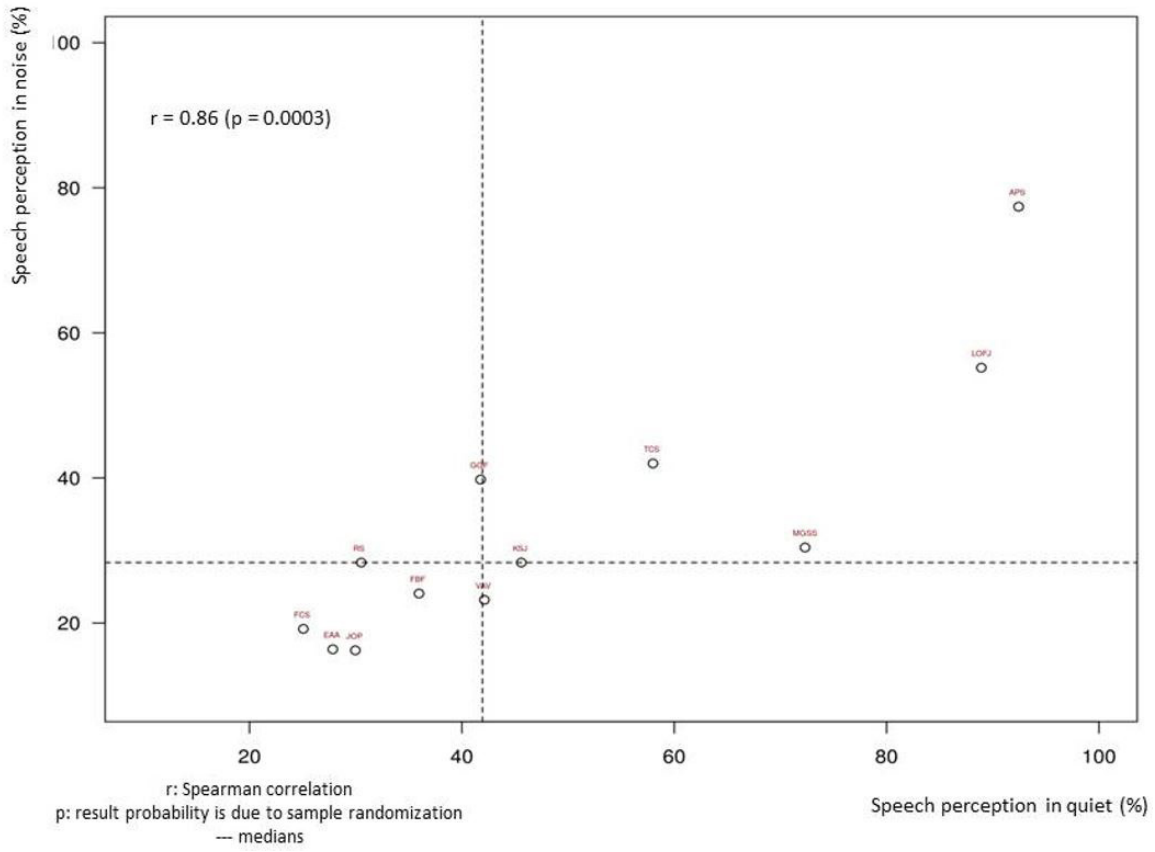

Figure 2. Correlogram between speech perception in the absence and the presence of competing noise
The acronyms in the figure correspond to the initials of the research participants

Table 4. Association between side and speech perception, in relation to the presence or not of competing noise

Side	n	[Minimum-Maximum]; Md (IQI)	d (p*-value)
Without competing noise	-	-	0.02 (0.0812)
Right	7	[25.1-92.4]; 36.0 (43.3)	-
Left	5	[26.8-72.3]; 42.1 (3.8)	-
With competing noise	-	-	0.14 (0.4881)
Right	7	[16-77]; 28 (27)	-
Left	5	[16-40]; 28 (7)	-

Subtitle: n = number of patients participating in the research; Md = median; IQI = interquartile interval; d = standardized difference; *p = result probability is due to sample randomization

DISCUSSION

It was observed in this study that the CI had beneficial effects on the studied population's speech perception, right after the first three months of use, both in the presence and the absence of competing noise, considering that speech perception before the surgery was zero (data collected from their medical record), without support from orofacial reading. Such data leads to the belief that the indication of CI is the most appropriate for adults with postlingual hearing loss, not benefitted with the HA[1,5,14]. This length of time established for initial assessment of hearing improvement was also observed in other studies, although the individual variation is an important aspect to be considered, as well as the fact that speech perception tends to improve as CI is used for longer[15,16]. It is worth highlighting that all the participants in the research underwent post-implantation auditory rehabilitation therapy at least once a week, besides systematically using the device. These facts have proved to be of help in reestablishing the impaired auditory skills caused by hearing loss[17].

The age median was 39 years – the young adults were the most frequent age group in other studies assessing speech perception in CI-using postlingual patients[18,19]. When it comes to individuals whose maximum age is 52.6 years, no relevant differences in performance regarding speech perception were to be expected, as it begins to decline from 70 years old, due to the deterioration of the auditory pathway from the spiral ganglion to the cortex and the decline in temporal processing[14,20,21]. Furthermore, it is known that the earlier an individual with postlingual hearing loss receives a CI greater are the possibilities of reducing the effects on the auditory cortex caused by advancing age itself[15].

The most prevalent etiology was the progressive with unknown origin, followed by ototoxicity and traumatic brain

injury; these etiologies were equally more prevalent in other studies conducted with adults with postlingual hearing loss[19,22,23]. It is also known that the etiology is a factor that interferes with the auditory result obtained with the implant; therefore, it is important to know what led to the person's hearing loss to have an idea of the implant's prognosis[24]. The fact that most etiologies are unknown can also be due to their being treated at a public (SUS) health care service, which receives patients from different socioeconomic classes and schooling levels. Therefore, oftentimes the cause of the hearing loss cannot be determined, as there is little information on the part of the patients and their companions when the multidisciplinary team is evaluating them, as well as difficulty in conducting in-depth etiological investigations.

The median of speech perception with no competing noise after three months using speech processor was 41.9, whereas the median of speech perception with competing noise in the speech test was 28.3. The performance is expected to be better in no competing noise circumstances, as the CI is a device originally developed to improve the user's speech perception, especially in favorable acoustic environments. The performance without the presence of competing noise was also notedly better in various other studies that aimed to compare speech perception in both situations[7,8,25].

Likewise, a positive correlation between speech perception in the absence and the presence of noise was demonstrated, showing that as speech perception without competing noise increases so does the perception with noise, and vice-versa. Such fact also demonstrates that it is not much likely that this variation is due to the randomly drawn list of phrases used in the test; moreover, these lists are equivalent in their degree of difficulty[13]. Therefore, it is reasonable to consider that the directionality technology studied can have contributed to the good performance in the speech tests, both in the presence and the absence of competing noise, since it was demonstrated that no variables other than time interfered with the result, as the individual was compared with themselves.

There was no correlation between the implanted side, the time of auditory deprivation without using HA and the implanted side after the first three months and with the same directionality. Such data agree with other studies, in which no side was observed to be better to implant than the other. The choice, then, is based on the presence of residual hearing – the greater it is in adults better is the speech perception – because residual hearing in one or both ears can maintain the central auditory pathway skill of decoding speech information. This is so even when the information arrives only through a CI, as the sound information provided through this device is still highly degraded, despite the evolution in sound decoding strategies[5,26,27].

According to some studies, the time of auditory deprivation is not a factor that contraindicates performing a CI. However, the earlier the device is implanted the better are the results obtained, because intrinsic modifications of the primary auditory cortex increase along with the extended time of auditory deprivation[2,28]. In adults with postlingual hearing loss, the auditory system had already developed but suffered alterations, as when the cortex regions responsible for auditory processing are altered to visual processing – which can result from the deterioration of phonological memory and increased use of orofacial reading[29]. Considering that progressive hearing loss was the most prevalent in the population studied, perhaps the effects of auditory deprivation were reduced regarding the loss of auditory processing functional capacity as well.

It is known that the data related to the asymmetry of normal auditory function, hemispheric specialization, and central auditory system modifications resulting from hearing loss must be considered in auditory performance with the CI[30]. Nevertheless, this study did not aim to evaluate issues related to laterality, hemispheric dominance, or auditory processing alterations; instead, it aimed to investigate whether the directionality of the CI processor's microphones aid in the patients' speech perception.

This study is limited by the fact that these patients' auditory processing assessments were not available to know which auditory skills were more altered; this could interfere in the results of speech perception. Nonetheless, everyone was compared to themselves, which allows the beforehand statement that directionality can have helped improved performance. This reinforces the importance of conducting further research, especially concerning the directionality of the microphones and the noise reduction systems in CI processors.

CONCLUSION

There was an improvement in speech perception after three months using the automatic tri-mode and the Opti Omni directionality, both with and without competing noise.

Similarly, it was observed that after three months using the Neuro™ implant system, there was a strong positive correlation between the speech perception with and without competing noise, demonstrating that there was an increase in speech perception with the directionality used, both in the absence and the presence of noise.

There was no correlation between the implanted side, the time of auditory deprivation, and the speech perception results with and without competing noise.

REFERENCES

1. Goffi-Gomez MVS, Guedes MC, Sant'Anna SBG, Peralta CGO, Tsuji RK, Castilho AM, et al. Critérios de seleção e avaliação médica e audiológica dos candidatos ao implante coclear: protocolo HC-FMUSP. Int Arch Otorhinolaryngol. 2004;8(4):22.
2. Canale A, Dalmasso G, Dagna F, Lacilla M, Montuschi C, Rosa RD, et al. Monaural or binaural sound deprivation in postlingual hearing loss: cochlear implant in the worse ear. Laryngoscope. 2016;126(8):1905-10. http://dx.doi.org/10.1002/lary.25774. PMid:26542290.
3. Lassaletta L, Calvino M, Sánchez-Cuadrado I, Pérez-Mora RM, Gavilán J. Which ear should we choose for cochlear implantation in the elderly: the poorer or the better? Audiometric outcomes, quality of sound, and quality-of-life results. Acta Otolaryngol. 2015;135(12):1268-76. http://dx.doi.org/10.3109/00016489.2015.1077391. PMid:26493303.
4. Medina MDM, Polo R, Gutierrez A, Muriel A, Vaca M, Perez C, et al. Cochlear implantation in postlingual adult patients with long-term auditory deprivation. Otol Neurotol. 2017;38(8):e248-52. http://dx.doi.org/10.1097/MAO.0000000000001257. PMid:28806334.
5. Huinck WJ, Mylanus EAM, Snik AFM. Expanding unilateral cochlear implantation criteria for adults with bilateral acquired severe sensorineural hearing loss. Eur Arch Otorhinolaryngol. 2019;276(5):1313-20. http://dx.doi.org/10.1007/s00405-019-05358-z. PMid:30810818.

6. Wesarg T, Voss B, Hassepass F, Beck R, Aschendorff A, Laszig R, et al. Speech perception in quiet and noise with an off the ear ci processor enabling adaptive microphone directionality. Otol Neurotol. 2018;39(4):e240-9. http://dx.doi.org/10.1097/MAO.0000000000001749. PMid:29533332.

7. Wu Y-H, Stangl E, Chipara O, Hasan SS, Welhaven A, Oleson J. Characteristics of real-world signal to noise ratios and speech listening situations of older adults with mild to moderate hearing loss. Ear Hear. 2018;39(2):293-304. http://dx.doi.org/10.1097/AUD.0000000000000486. PMid:29466265.

8. Kolberg ER, Sheffield SW, Davis TJ, Sunderhaus LW, Gifford RH. Cochlear implant microphone location affects speech recognition in diffuse noise. J Am Acad Audiol. 2015;26(1):51-8, quiz 109-10. http://dx.doi.org/10.3766/jaaa.26.1.6. PMid:25597460.

9. Kordus M, Tyler RS, Żera J, Oleson JJ. An influence of directional microphones on the speech intelligibility and spatial perception by cochlear implant users. Arch Acoust. 2015;40(1):81-92. http://dx.doi.org/10.1515/aoa-2015-0010.

10. Oticon Medical. Direcionalidade Free Focus. 2017.

11. Weile JN, Littau B. Free Focus. Somerset, NJ: Oticon; 2013. 4 p. Technical paper.

12. Nascimento LT, Bevilacqua MC. Avaliação da percepção da fala com ruído competitivo em adultos com implante coclear. Rev Bras Otorrinolaringol. 2005;71(4):432-8. http://dx.doi.org/10.1590/S0034-72992005000400006.

13. Costa MJ, Santos SN, Lessa AH, Mezzomo CL. Proposal for implementing the Sentence Recognition Index in individuals with hearing disorders. CoDAS. 2015;27(2):148-54. http://dx.doi.org/10.1590/2317-1782/20150000316. PMid:26107080.

14. Forli F, Lazzerini F, Fortunato S, Bruschini L, Berrettini S. Cochlear implant in the elderly: results in terms of speech perception and quality of life. Audiol Neurotol. 2019;24(2):77-83. http://dx.doi.org/10.1159/000499176. PMid:31117068.

15. Dowell RC. The case for earlier cochlear implantation in postlingually deaf adults. Int J Audiol. 2016;55(Suppl 2):S51-6. http://dx.doi.org/10.3109/14992027.2015.1128125. PMid:26918896.

16. Massa ST, Ruckenstein MJ. Comparing the performance plateau in adult cochlear implant patients using HINT and AzBio. Otol Neurotol. 2014;35(4):598-604. http://dx.doi.org/10.1097/MAO.0000000000000264. PMid:24557031.

17. Baungaard LH, Sandvej MG, Krøijer JS, Hestbæk MK, Samar CF, Percy-Smith L, et al. Auditory verbal skills training is a new approach in adult cochlear implant rehabilitation. Dan Med J. 2019;66(3) PMid:30864546.

18. Vieira SS, Dupas G, Chiari BM. Repercussões do implante coclear na vida adulta. CoDAS. 2018;30(6):e20180001. http://dx.doi.org/10.1590/2317-1782/20182018001. PMid:30517268.

19. Czerniejewska-Wolska H, Kałos M, Gawłowska M, Sekula A, Mickiewicz P, Wiskirska-Woźnica B, et al. Evaluation of quality of life in patients after cochlear implantation surgery in 2014-2017. Otolaryngol Pol. 2019;73(2):11-7. http://dx.doi.org/10.5604/01.3001.0013.0400. PMid:30919822.

20. Sharpe RA, Camposeo EL, Muzaffar WK, Holcomb MA, Dubno JR, Meyer TA. Effects of age and implanted ear on speech recognition in adults with unilateral cochlear implants. Audiol Neurotol. 2016;21(4):223-30. http://dx.doi.org/10.1159/000446390. PMid:27450677.

21. Duarte M, Gresele ADP, Pinheiro MMC. Temporal processing in postlingual adult users of cochlear implant. Rev Bras Otorrinolaringol. 2016;82(3):304-9. PMid:26642753.

22. Cunningham LL, Tucci DL. Hearing loss in adults. N Engl J Med. 2017;377(25):2465-73. http://dx.doi.org/10.1056/NEJMra1616601. PMid:29262274.

23. Manrique M, Ramos Á, de Paula Vernetta C, Gil-Carcedo E, Lassaletta L, Sanchez-Cuadrado I, et al. Guía clínica sobre implantes cocleares. Acta Otorrinolaringol Esp. 2019;70(1):47-54. http://dx.doi.org/10.1016/j.otorri.2017.10.007. PMid:29598832.

24. Calháu CMDF, Lima LRP Jr, Reis AM, Capistrano AK, Lima DV, Calháu AC, et al. Etiology profile of the patients implanted in the cochlear implant program. Rev Bras Otorrinolaringol. 2011;77(1):13-8. PMid:21340183.

25. Goehring T, Keshavarzi M, Carlyon RP, Moore BCJ. Using recurrent neural networks to improve the perception of speech in non-stationary noise by people with cochlear implants. J Acoust Soc Am. 2019;146(1):705-18. http://dx.doi.org/10.1121/1.5119226. PMid:31370586.

26. Derinsu U, Yüksel M, Geçici CR, Çiprut A, Akdeniz E. Effects of residual speech and auditory deprivation on speech perception of adult cochlear implant recipients. Auris Nasus Larynx. 2019;46(1):58-63. http://dx.doi.org/10.1016/j.anl.2018.06.006. PMid:29945747.

27. Pisoni DB, Kronenberger WG, Harris MS, Moberly AC. Three challenges for future research on cochlear implants. World J Otorhinolaryngol Head Neck Surg. 2018;3(4):240-54. http://dx.doi.org/10.1016/j.wjorl.2017.12.010. PMid:29780970.

28. Lazard DS, Giraud A-L, Gnansia D, Meyer B, Sterkers O. Understanding the deafened brain: implications for cochlear implant rehabilitation. Eur Ann Otorhinolaryngol Head Neck Dis. 2012;129(2):98-103. http://dx.doi.org/10.1016/j.anorl.2011.06.001. PMid:22104578.

29. McKay CM. Brain plasticity and rehabilitation with a cochlear implant. Adv Otorhinolaryngol. 2018;81:57-65. http://dx.doi.org/10.1159/000485586. PMid:29794427.

30. Buarque LFSFP, Brazorotto JS, Cavalcanti HG, Lima LRP Jr, Lima DVSP, Ferreira MAF. Desempenho auditivo ao longo do tempo em usuários de implante coclear com perda auditiva pós-lingual. Audiol Commun Res. 2013;18(2):120-5. http://dx.doi.org/10.1590/S2317-64312013000200010.