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ORIGINAL ARTICLE

Temporal processing in postlingual adult users of cochlear implant^{☆,☆☆}



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KEYWORDS

Cochlear implant;
Hearing tests;
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Abstract

Introduction: Postlingual adults demonstrate impressive performance in speech recognition in silence after cochlear implant (CI) surgery. However, problems in central hearing abilities remain, which complicates understanding in certain situations, such as in competitive listening and in the perception of suprasegmental aspects of speech.

Objective: To assess the temporal processing abilities in postlingual adult users of CI.

Methods: Cross-sectional and descriptive study, with a non-probabilistic sample for convenience. The population was divided into two groups. The study group consisted of 12 postlingual adult users of cochlear implants and the control group consisted of 12 adults with normal hearing, matched for age and gender with the control group. The Frequency Pattern Test and the Gaps in Noise test were selected to assess temporal processing. Free-field testing was applied at 50 dB SL.

Results: Adult users of cochlear implant attained a mean temporal threshold of 16.33 ms and scored 47.7% in the pattern frequency test; the difference was statistically significant in comparison with the control group.

Conclusion: It was verified that postlingual adult users of cochlear implants have significant alterations in temporal processing abilities in comparison to adults with normal hearing.

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PALAVRAS-CHAVE

Implante coclear;
Testes auditivos;
Adulto;
Audição;
Perda auditiva

Processamento temporal em adultos pós-linguais usuários de implante coclear**Resumo**

Introdução: Os adultos pós-linguais apresentam ótimo desempenho no reconhecimento de fala no silêncio após a cirurgia de implante coclear. No entanto, permanecem com alterações nas habilidades auditivas centrais, dificultando a compreensão em situações de escuta competitiva e na percepção dos aspectos supra-segmentais da fala.

Objetivo: Avaliar as habilidades do processamento temporal em adultos pós-linguais usuários de implante coclear.

Método: O estudo foi do tipo transversal, descritivo com amostra não-probabilística por conveniência. A população foi distribuída em dois grupos. O grupo estudo foi composto por 12 adultos pós-linguais usuários de IC e o grupo controle por 12 adultos com audição normal pareados conforme faixa etária e sexo do grupo estudo. Para avaliar o processamento temporal foi selecionado o Teste Padrão de Frequência e o teste *Gaps in Noise*. Os testes foram aplicados em campo livre e a 50 dB NS.

Resultados: Os adultos pós-linguais usuários de IC obtiveram limiar de acuidade temporal médio de 16,33 ms e desempenho de 47,7% de acertos no teste padrão de frequência, sendo que a diferença foi estatisticamente significativa em relação ao grupo controle.

Conclusão: Foi constatado que os adultos pós-linguais usuários de IC apresentam alterações nas habilidades do processamento temporal em relação aos adultos sem alterações auditivas.

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Introduction

Currently, the cochlear implant (CI) is considered the most effective clinical resource to rehabilitate the hearing of patients who have not benefitted from the use of an individual sound amplification device (ISAD).¹

Postlingual adult users of CI have excellent results with the device, and are able to reach the maximum score in tests of speech recognition in silence.^{2,3} However, these patients still persist with alterations in central hearing abilities, making speech understanding difficult in some situations. Among the affected hearing abilities, temporal processing is one of the most affected aspects.⁴

Temporal hearing processing involves the ability to process the sound aspects that vary over time. It includes resolution hearing abilities, ordering, masking, and temporal integration.⁵ Currently, only ordering and temporal resolution abilities are routinely included in behavioral tests, because there are no available and standardized tests to assess the other abilities.⁶

The temporal resolution hearing ability helps the individual to identify small acoustic variations that occur in the speech signal over time, and allows the perception of segmental, syllabic, and word distinctions in continuous speech.⁷ This ability can be evaluated through behavioral tests of gap detection. The Gaps-in-Noise (GIN) test has been recommended in the current studies as a reliable tool to assess the temporal resolution hearing ability in children, adults, and the elderly.^{8–10}

Temporal ordering comprises a hearing ability that involves the perception and processing of two or more hearing stimuli according to their order of occurrence in time.¹¹ This ability can be evaluated through tests involving the recognition of the temporal pattern of pure tones, such

as the Frequency Pattern Test (FPT), which is considered a sensitive tool to identify central nervous system lesions.¹²

There are some studies in the literature suggesting that the temporal processing abilities are directly associated with speech perception.^{13,14} The argument supporting this proposition is that many characteristics of hearing information are somehow influenced by temporal aspects.⁵

However, there are few studies in the literature evaluating the temporal processing abilities in the population of CI users. Among these investigations, the studies by Daniels and Musiek,¹⁵ Comerlato Jr.,¹⁶ and Soares et al.¹⁷ used a standardized test to assess the temporal resolution ability. The studies by Frederigue¹⁸ and Campos et al.¹⁹ assessed the hearing ability of temporal ordering in this population.

Given the importance of the temporal aspects of speech, music and reading perception, it is very important to assess the performance of CI users in temporal tests. These results may suggest a better strategy of CI programming, as temporal processing influences the aspects of time and duration of speech. Based on these facts, some authors have suggested new studies with standardized tests to investigate the hearing abilities of temporal processing in this population.¹⁶

Based on the above, the aim of this study was to evaluate the temporal processing abilities in postlingual adult users of CI.

Methods

This study was carried out from February to July 2014 at the Speech Therapy Course School Clinic, Universidade Federal de Santa Catarina. The research was initiated only after approval by the Ethics Committee in Research with Human Beings, protocol No. 11366613.6.0000.0121. Individuals who agreed to participate signed the informed consent.

This research followed a quantitative, descriptive, and cross-sectional approach, and consisted of a non-probabilistic convenience sample.

The sample was divided into two groups: study group (SG) and control group (CG). The SG consisted of 12 adult users of CI, aged between 24 and 69 years, with postlingual deafness; the CG consisted of 12 normal hearing adults. The control group was matched for age and gender with the SG.

In order to be included in the protocol and undergo the temporal tests, the SG group included CI users who met the following criteria: lack of evidence of neurological or cognitive alterations that would prevent the understanding of the given commands, bilateral severe-to-profound sensorineural hearing loss,²⁰ hearing thresholds in free field between 25 and 40 dB HL at 250–4000 Hz frequency, who were adult CI users with post-lingual deafness with a minimum time of 12 months using the device, with full insertion of electrodes in the cochlea, and for whom Portuguese language was the first language, in addition to showing speech recognition in the open set sentence test >80%.²¹

The CG included adult individuals without hearing alterations that showed no evidence of neurological or cognitive changes that would prevent them from understanding the given commands, had bilateral hearing thresholds within the normal range,²⁰ no complaints that could indicate alterations in the central auditory processing (CAP) in the questionnaire proposed by Summers,²² and normal results in the Dichotic Digit Test.²³

Regarding the procedures performed by the SG, the hearing thresholds were initially tested at the frequencies of 500, 1000, 2000, 3000, 4000, 6000, and 8000 Hz. The test was performed in free field, with the speakers at a distance of one meter from the patient, who was positioned at 0° azimuth in the horizontal and vertical planes. This procedure was performed to quantify the level of sensation that was used in the temporal processing tests. If the patient was a contralateral ISAD user, he/she was asked to remove the prosthesis and remain only with the CI.

Regarding the procedures performed with the CG, a questionnaire proposed by Summers²² was applied to rule out complaints of central auditory processing disorder (CAPD). The normality criterion established for this questionnaire was 45 points.

Afterward, the hearing thresholds were tested at the frequencies of 250, 500, 1000, 2000, 3000, 4000, 6000, and 8000 Hz, aiming to verify whether the hearing thresholds of both ears were within the normal range according to Lloyd and Kaplan.²⁰ The measurements were performed in a soundproof booth, using a two-channel digital audiometer, model AC40, manufactured by Interacoustic, and Wilfan TDH 39 earphones.

Tympanometry as well as ipsilateral and contralateral stapedial acoustic reflexes were also tested. The tympanometric curves according to Jerger²⁴ and acoustic reflexes according to Gelfand²⁵ were considered normal. This procedure sought to assess any middle ear involvement in the control group, which could interfere with the study outcomes and was performed with an AT235 acoustic immittance device, according to ISO 389 calibration standards.

Another procedure performed with the CG was the Dichotic Digit Test (DDT), as the authors Jerger and Musiek²⁶ propose its use as a screening test to rule out a possible

alteration in auditory processing. Therefore, all adults who had a total of at least 95% test accuracy were included in the CG.²³ Of the CAP tests, the latter was the only one applied with supra-aural phones, using the sensation level of 50 dB HL.

After performing the abovementioned procedures, both groups were submitted to the assessment of auditory temporal processing. The GIN²⁷ and FPT²⁸ tests were used. The GIN test consists of the detection of gaps inserted into white noise. These gaps can be of 2–6, 10, 12, 15, and 20 ms. For individuals who were unable to identify the maximum gap, a 22-ms interval was assigned. The GIN test was applied in order to assess the hearing ability of temporal resolution, in addition to determining the temporal acuity threshold and the percentage of correct answers. The training track and the test tracks 1 and 2 of the compact disc were used.

The FPT was used to assess the performance of individuals evaluated regarding the hearing ability of temporal ordering. In this test, the patient was instructed to name the tonal pattern heard in order of occurrence. The stimuli were presented with six sequences in the training stage and 30 in the evaluation sequence. A qualitative analysis of FPT was also performed in order to verify the most common types of errors made by implant users. These were classified as inversion errors when all sounds were discriminated, but in different orders, for instance: GAG mistaken for AGA; or as discrimination errors when the pronounced sounds were replaced, for instance: GGA mistaken for AAG.

All tests were performed with a two-channel audiometer manufactured by Interacoustic (model AC40) coupled to a Samsung computer (model NP300E4C) that displayed the recorded tests. The temporal tests were applied in a sound-proof booth and in free field at 50 dB SL. Patients were placed at 0° azimuth in the horizontal and vertical planes.

Tests in the SG were carried out exclusively with the CI. The majority of patients had more than one program recorded in the speech processor. The tests were conducted with the program in which the patient showed better responses in the open set sentence tests²¹ and with the coding strategy used on the assessment day.

Statistical analysis was carried out with the following software: SPSS v. 17, Minitab v. 16, and Office Excel 2010. The nonparametric Mann–Whitney test was used to compare the performance between the CG and SG in the GIN and FPT tests. The level of significance was set at 5% for all tests ($p \leq 0.05$).

Results

The SG population consisted of 12 subjects, four (33.3%) males and eight (66.6%) females. The age range of CI users ranged from 24 to 69 years of age, with a mean of 49 years. Regarding schooling, it was observed that 58.3% of patients finished elementary school and only one (8.3%) had completed college/university.

The tables and Fig. 1 show the performance of the SG and CG in the GIN test.

According to the results shown in Table 1, it was observed there was a statistically significant difference between the CG and SG at the GIN test, both in the temporal acuity threshold as well as in the percentage of gap recognition

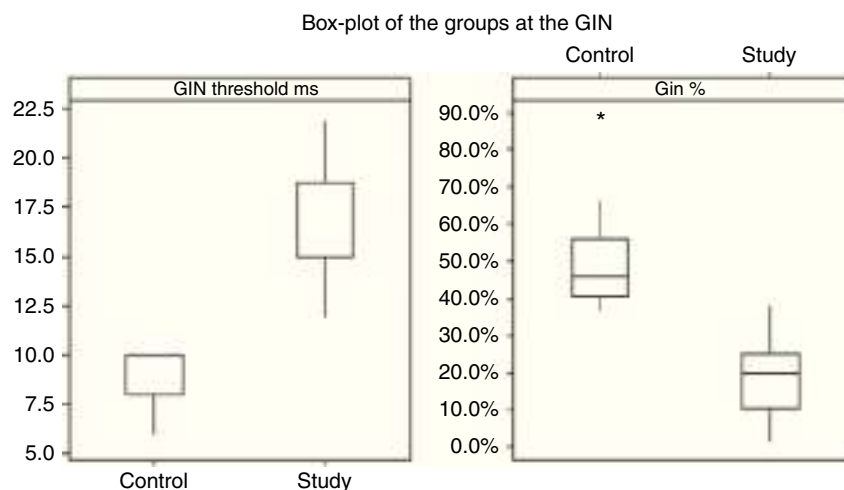


Figure 1 Control group and study group performance at the Gaps-in-Noise test.

Table 1 Descriptive statistics of the Gaps-in-Noise (GIN) test performance according to the group.

GIN group	Mean	Median	Standard deviation	Q1	Q3	n	CI	^a p-Value
<i>GIN_Thres</i>								
CG	8.33	8	1.44	8	10	12	0.81	<0.001
SG	16.33	15	3.17	15	16.25	12	1.79	
<i>GIN_%</i>								
CG	51.1%	45.8%	14.6%	42.5%	55.4%	12	8.3%	<0.001
SG	19.1%	20.0%	10.0%	14.5%	22.9%	12	5.7%	

CG, control group; SG, study group; Q1, first quartile; Q3, third quartile; GIN_Thres, temporal acuity threshold; GIN_%, gap recognition percentage.

^a Mann-Whitney test.

($p=0.001$). It is observed that in the GIN test, for both the threshold and percentage, the CG had better results than the SG. These results are better visualized in Fig. 1.

Table 2 shows that there was a statistically significant difference between the performance of the groups in the FPT test. It is observed that CI users have worse performance when compared to adults without hearing impairment. This finding can be better visualized in Fig. 2.

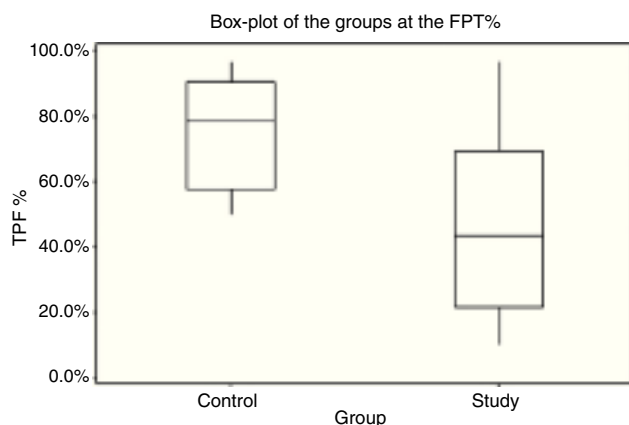


Figure 2 Control group and study group performance at the Frequency Pattern Test.

In order to better characterize the study group, a brief qualitative description of the FPT results was constructed, based on the types of errors made by the subjects.

It was observed that of the 12 tested individuals, only two showed no inversion of frequency patterns, and all showed some type of discrimination error. The mean percentage of inversions in the FPT test was 14.4%, with 28.6% discrimination. Other phenomena, such as the omission and insertion of tones, were also observed in the FPT.

Discussion

The mechanisms involved in speech perception are closely related to the complex integration between detection, discrimination, recognition, categorization, sequential shapes, and the rhythm of speech sounds. The processing of acoustic clues from speech sounds is related to the adequate perception of the frequency and duration spectra in their order of occurrence, in addition to the perception of sound modifications over time.^{7,29}

Behavioral tests that assess the temporal hearing processing abilities can be carried out in the postoperative follow-up of patients using CI. The analyses of these tests may provide important information on the performance of individuals in relation to speech perception and the central auditory abilities.

Table 2 Descriptive statistics of Frequency Pattern Test (FPT) test performance according to the group.

Group	Mean	Median	Standard deviation	Q1	Q3	n	CI	^a p-Value
FPT								
CG	76.1%	78.3%	16.7%	59.2%	90.0%	12	9.4%	0.013 ^a
SG	47.7%	43.3%	28.9%	31.6%	67.5%	12	16.3%	

CG, control group; SG, study group; Q1, first quartile; Q3, third quartile.

^a Mann-Whitney test.

The present study showed that CI users had significant difficulties to detect gaps in noise (Table 1 and Fig. 1), demonstrating alteration in temporal resolution ability. It is noteworthy that in the SG, ten CI users were able to detect the gap at the maximum interval of 20 ms.

These findings corroborate the work of Daniels and Musiek¹⁵ and Comerlato Jr.,¹⁶ in which they found that CI users have significantly greater difficulty in detecting gaps in noise when compared to subjects with normal hearing.

The findings of this research and the data found in literature show that electrical stimulation performed by CI demonstrates major differences when compared to the natural stimulation of the cochlea. This occurs because the CI has limited spectral discrimination of the temporal aspects of sound, which are significantly important to facilitate the process of speech understanding.³⁰

Thus, it is inferred that cochlear impairment observed in CI users directly influences the detection of gaps in the noise and that the CI does not provide sufficient temporal information to promote adequate temporal resolution.

Although postlingual adults show alterations in temporal resolution, literature reports have shown that these users have significantly higher performance when compared to prelingual CI users. In the study by Wei et al.,³¹ it was found that CI users showed temporal acuity threshold of 10 ms, while the prelingual obtained a threshold of 40 ms. This difference between the two groups is in line with other studies that showed that the hearing benefits in postlingual CI users are higher than in the prelingual.³²

Also, it should be observed that there is a study in the literature¹⁴ that evaluated postlingual CI users and found that these individuals were able to identify the silent interval with a similar performance to adults without hearing impairment. It is noteworthy; however, that the stimulus used in the research was synthetic vowels created by the authors, which is a different stimulus from that used in this research and the other aforementioned studies. According to Samelli and Schochat,¹³ the different stimuli and test presentation forms can result in very discrepant gap thresholds. The authors also add that there are different markers, with differences in gap intensity, duration, and position inside the markers, in addition to the effect of the signal rise time and signal fall time. All these aspects must be considered in the analysis of the findings.

Regarding the performance of CI users in the temporal ordering ability, this study showed that the individuals had significant difficulty in recognizing and ordering the frequency tones (Table 2 and Fig. 2). These results corroborate other studies found in literature,^{18,19} that showed a worse performance in the hearing ability of temporal ordering by CI users.

In the study by Frederigue,¹⁸ the FPT children's version developed by Auditec³³ was applied in children using CI and elicited a superior performance at the FPT when compared to the present research. This fact can be explained by the greater interval between stimuli present in the children's version of the FPT so that the tonal pattern recognition is facilitated.

However, it is believed that the change in the temporal ordering ability is closely related to the fact that CI users have high degrees of hearing loss and, consequently, changes in sound sensation and distortion in sound perception, caused by cochlear impairment.

The qualitative analysis of the FPT shown in the study (Table 3) allowed for verification that the most common types of inversions were the asymmetric patterns, such as GGA mistaken for AGG, and the opposite, AGG mistaken for GGA. However, most types of discrimination errors occurred when a different frequency tone was present in the middle of the sequence, for instance: AGA or GAG.

Based on this analysis it was observed that postlingual CI users showed more deficits in sound discrimination, a prerequisite for temporal ordering, and this is probably related to the fact that CI users have alterations in the reception of auditory stimuli. However, it is important that other studies with CI users assess the most common error patterns in this population, so that these data can be compared, as well as assisting in hearing rehabilitation.

The authors suggest that further researches investigate the abilities of temporal processing in larger populations of CI users, as one of the main difficulties was the few

Table 3 Types of errors in the study group in the Frequency Pattern Test.

Patients	Type of errors	
	Inversion	Discrimination
P1	3	11
P2	3	9
P3	1	8
P4	6	11
P5	9	4
P6	3	11
P7	8	13
P8	4	12
P9	0	1
P10	0	2
P11	2	8
P12	13	13
Total	52	103

studies in the literature to serve as comparison parameter. The population of implanted individuals has many variables to be considered; this factor makes the analysis a quite difficult task. It is believed that new studies with more homogeneous populations can better characterize the findings.

However, it is expected that the major alterations in the temporal aspect in postlingual adults assessed in this study can contribute to emphasize how important it is for hearing rehabilitation to focus on frequency, intensity, and duration parameters, so that individuals experience better quality communication in their various everyday environments.

Conclusion

The hearing abilities of temporal processing are altered in postlingual adult CI users. The performance in the GIN and FPT tests in this population was significantly worse when compared to adults of the same age without hearing loss.

Conflicts of interest

The authors declare no conflicts of interest.

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