Behavioral and Electrophysiological Assessment of Adults Who Underwent Cochlear Implantation After Hearing Aid Experience*

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Abstract

Introduction   Cochlear implantation has been considered a viable option to restore hearing perception in adults with severe to profound postlingual hearing loss.

Objectives   To analyze behavioral hearing responses and P300 latency and amplitude measurements in adults with bilateral sensorineural hearing loss at two phases, first when they were using hearing aids (HAs) and, then, after 12 months of cochlear implant (CI) use. The association between behavioral and electrophysiological evaluations was explored, as it is believed that the study of auditory processing with different hearing devices can contribute to future CI adjustments and fittings, especially for patients who cannot give subjective feedback (such as small children and individuals with multiple disabilities).

Methods   Prospective comparative study (Ethical approval 11489/2014). Twelve adults were assessed, 7 males and 5 females, in the 22 to 76 years old age range, who had undergone CI surgery after HA experience.

Results   The analyses showed an improvement of hearing thresholds when patients started using CIs. Comparing data from P300 latency measurements, there was an increase of the P300 wave post-CI at Cz and Fz. Regarding the amplitude, P300 mean values decreased at Cz, but increased at Fz. There was no significant correlation between behavioral and electrophysiological assessment and the variables age, gender, auditory deprivation, and electronic device used.

Keywords
► event-related potentials
► P300
► cochlear implantation
► adult
► hearing loss

Conclusion   There was a significant improvement of hearing thresholds after twelve months of CI experience. The mean latency values of P300 after 12 months of CI use increased at Cz and Fz, while mean amplitude values decreased at Cz and increased at Fz.

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Introduction

Individuals with severe to profound hearing loss are known to receive little to no benefit with the use of hearing aids (HAs). In those cases, cochlear implants (CIs) are an efficient alternative, which can provide a high speech recognition rate.[1]

This device projects sound to be received by a microphone and be sent to a speech processor, which digitally codifies speech through different strategies that vary according to the device's manufacturer. Signal is then sent by a transmitter to an internal stimulator, which converts signal into electrical impulses sent to electrodes inside of the cochlea. Thus, electrodes stimulate the cochlear nerve, and impulses can travel along the auditory system.[2]

Currently, there is a need to determine audiological parameters for CI indication and, especially, for patients' follow-up. Behavioral assessment of CI patients, through speech perception tests and self-assessment questionnaires, has been a common procedure; however, there is a concern presented by audiologists regarding objective assessments, specifically electrophysiological tests, aiming to investigate the central auditory nervous system (CANS). Auditory evoked potentials, particularly cognitive ones, which are obtained by recording and measuring responses to sensorial stimuli captured on the cranial surface, have been under investigation, with the purpose of investigating possible changes in the CANS, such as neural plasticity, after CI stimulation.

Among other cognitive auditory evoked potentials, P300 provides a neurophysiological assessment of cognitive function, since it is evoked by the conscious interaction between the hearing system and the somatosensory cortex, and it depends on the attention and participation of the subject to elaborate responses.[3,4] The P300 data are collected through random presentations of a rare acoustic stimulus previously established among other frequent stimuli ("oddball" paradigm). The endogenous perception of rare stimuli will provide necessary data for the elicitation of waves. The analyzed waves can bring information on the treatment of hearing disorders and reflect on the electrophysiological activity involved during attention, discrimination, memory, integration and decision-making abilities.[5]

The P300 is included in the long latency auditory evoked potentials (LLAEPs), which can be observed approximately between 80 and 700 ms after an acoustic stimulus presentation.[6] Studies show a wide variety of amplitude values for this potential, which can vary according to task and attention.

The P300 has been tested with the CI population and is gradually being included in clinical practice. Studies have measured P300 waves in children and adults with HAs and CIs, showing that this kind of research is viable; however, more studies with P300 in adult CI users are needed to demonstrate its applicability.[7–10] Hopefully, the results obtained in this study can contribute, along with behavioral tests, as sensitive indicators of the processing functions in these patients and therefore help us in the assessment of CI candidates.

Thus, the aim of this study was to analyze the auditory behavioral and electrophysiological responses, latency and amplitude values of the P300 potential, in adults with bilateral profound sensorineural hearing loss, HA users submitted to cochlear implantation.

Methods

The present study is a transversal prospective comparative and correlational one, with emphasis on diagnostic research.

The project was approved by the Institutional Review Board (IRB), ethical approval 11489/2014, CAE number 32404514.9.0000.5440 (Doc. 1.255.971).

Participants

Twelve adults participated in the present study, seven male and five female. To fulfill the inclusion criteria, subjects were required to have bilateral postlingual sensorineural hearing loss and be submitted to CIs after bilateral HA experience.

Procedures

Data were collected in two phases. The 1st one was prior to CI surgery, when the subjects were using HAs, and the 2nd one was at least 12 months after CI activation. Both phases were performed in the same conditions.

In the hearing health program where this study was conducted, the audiological assessment of CI candidates investigates their hearing and language conditions, and consists of the following procedures: pure tone audiometry and speech perception tests with supra-aural earphones, electrophysiological assessment (brainstem evoked response audiometry and cortical auditory evoked potentials—P300), as well as audiometry and speech perception tests in free field, with HAs.

On the 2nd phase, participants were reevaluated with puretone audiometry and P300. Audiometry was performed in free field, with the AC 40 audiometer (Interacoustics, Middelfart, Denmark), considering frequencies from 250 to 8,000 Hz, and the subject was seated, in an acoustically treated environment.

Mean hearing thresholds were calculated by the following frequencies: 500, 1,000, 2,000 e 4,000 Hz.

To obtain P300 measures, the two-channel Bio-logic equipment (Navigator® Pro from Bio-logic® Systems Corp. Auditory Evoked Potential - AEPSystem, 1.3.0 version/Natus Medical, USA), connected to a conventional computer, was used to register the auditory evoked potentials. Active electrodes were positioned at Cz and Fz, connected to entry 1 of the preamplifier; channels 1 and 2. Reference electrodes were connected to entry 2 of channels 1 and 2 (jumper), from the preamplifier and placed on the left earlobe (A1). The earth electrode was placed on the right earlobe (A2). While testing, the individual impedance of electrodes was maintained at 5 KΩ or less, and the difference of impedance between them at 3 KΩ or less. The time window was shown as 512 ms, with a 50,000 μV gain, high-pass filters of 30 Hz and low pass of 100 Hz.

During the procedure, the subjects were in a semi-seated position, with their eyes open and fixed on a target point in front of them, to avoid eye movement artifacts. Tone bursts were chosen as auditory stimuli, with a frequency of 1,000 Hz for the frequent stimulus and 2,000 Hz for the rare stimulus,

Table 1 Characterization of subjects' audiological variables without the use of electronic hearing devices

Audiological Variables	Mean	Median	SD	Minimum	Maximum
Age at hearing loss (years)	18.08	10.00	16.78	0.00	49.00
Auditory deprivation time (years)	8.79	3.50	13.73	0.00	46.00
Age at HA fitting (years)	26.58	23.00	18.00	1.00	53.00
HA use time (years)	19.54	18.50	14.64	0.42	47.00
Average RE HT without HAs (dB HL)	110.55	112.00	9.02	85.00	118.00
Average LE HT without HAs (dB HL)	109.25	115.50	11.38	80.00	119.00
RE SPT results without HAs (%)	33.00	0.00	45.99	0.00	100.00
LE SPT results without HAs (%)	32.00	0.00	45.00	0.00	100.00

Abbreviations: dB HL, decibel hearing level; HA, hearing aid; HT, hearing thresholds; LE, left ear; RE, right ear; SD, standard deviation; SPT, speech perception test.

where 80% were frequent stimuli and 20% were rare stimuli, randomly presented, at an intensity of 90 dB. Measurements were taken in two successive passages to allow good definition and replication.

The P300 testing took place in free field, with the loudspeaker positioned at an azimuthal angle of 0° when subjects had bilateral HAs, and at 45° when subjects were then using a CI, positioned next to the speech processor, at a 60 cm distance.

For both phases, subjects were asked to identify the rare stimulus by slightly raising their index finger each time it appeared. Thus, behavioral responses in the presence of rare stimuli were observed and registered by the researchers to be then analyzed.[6,11,12] Wave tracing registrations were considered when there was replication of the tracing and when the subject identified the stimulus with a maximum of 10% stimulus deviation (50 ± 5 stimuli). Before starting to register the responses, subjects were exposed to the stimuli and trained so that they fully understood the task.

Behavioral registrations were made by two observers, individually, with no communication between them and behaviors were categorized as:

- Immediate response to rare stimulus;
- Late response to rare stimulus (less than 2 seconds);
- Incompatible response (raises finger in the absence of rare stimuli);

Cochlear implant brand and model were not variables that could be controlled, considering the study's institutional demand of equal distribution among brands, since it is a service accredited to the Unified Health System (SUS, in the Portuguese acronym. Public health system that grants elec-

tronic hearing devices, equally distributed by the accredited companies).[13–15]

Sample Profile

►**Table 1** shows the audiological data of the 12 participants, in which we can see that 10 were unilateral CI users and 2 were binaural CI users. Six of the subjects received CI surgery on the right ear, and six on the left ear. The average age was 46.5 years old, considering that the lowest age was 22, and the highest, 76.

►**Table 2** contains audiological data of the subjects during both phases of the study. Mean hearing thresholds with HAs when compared with mean hearing thresholds with CI show a difference of 43.92 dB HL. It is noticeable that the highest mean hearing threshold with CI was 51 dB HL, which belongs to one subject who did not perceive benefits from CI use, unlike the rest of the group. Regarding the speech perception test (SPT) results, higher percentage scores can be seen when subjects were in the CI phase.

The non-identification of hearing loss etiology represents 50% of the 12 subjects, and otosclerosis is the most frequent etiology, whereas other causes (mumps, bacterial meningitis, ototoxicity and mechanical trauma) appeared only once.

About the CI brands used in this study, Med-El (Innsbruck, Austria) was the most frequent one, followed by Cochlear (Sydney, Australia) and Advanced Bionics (Norwest, Australia), each with 3 subjects. Lastly, there were 2 subjects with Neurelec (Vallarius, France) Advanced Bionics (Los Angeles, USA). Each device has its own functional characteristics, which are described in ►**Table 3**.

Table 2 Characterization of Subjects' Audiological Variables with the Use of HA and CI

Audiological variables	Mean	Median	SD	Minimum	Maximum
Average HT with HAs (dB HL)	75.25	73.50	16.33	50.00	96.00
Average HT with CIs (dB HL)	31.33	29.00	8.85	17.00	51.00
Average SPT result with HAs (%)	28.20	9.00	34.49	0.00	80.00
Average SPT result with CIs (%)	68.42	81.50	34.54	0.00	100.00

Abbreviations: CI, cochlear implant; dB HL, decibel hearing level; HA, hearing aid; HT, hearing thresholds; LE, left ear; RE, right ear; SD, standard deviation; SPT, speech perception test.

Table 3 Characterization of cochlear implant devices used by the subjects of this sample ($n = 12$)

Subject	Device brand	Number of channels (n)	Speech coding strategies	Pulse rate per channel (pps)	Current (Hz)
1	Med-El	11	FS4	802	87.08
2	Cochlear	22	ACE	900	25
3	Neurelec	24	Crystalis XDP	500	–
4	Med-El	12	FS4	705	17.92
5	Cochlear	22	ACE	900	25
6	Ad. Bionics	16	Hires PWI Fidelity 120	3,712	18
7	Ad. Bionics	16	Hires S/Fidelity 120	3,712	18
8	Ad. Bionics	16	Hires P/Fidelity 120	2,652	26.9
9	Cochlear	22	ACE	1,200	25
10	Med-El	11	FS4	802	40
11	Neurelec	24	Crystalis	500	–
12	Med-El	12	FS4	750	50.42

Abbreviations: Ad., Advanced; CI, Cochlear implant; Hz, hertz; n, number; pps, pulses per second.

Data Analysis

An exploratory analysis took place, to summarize values, organize and describe data in two ways: through tables with descriptive measures and through graphs. Continuous variables were expressed as basic descriptive statistics and categorical variables were expressed as frequency and percentage. To reach the established aims, a linear mixed-effects regression model and Pearson correlation coefficient (r) were used. A significance level of 5% ($p \leq 0.05$) was adopted for all analyses and adjustments were obtained in the SAS software, version 9.2 (SAS Institute Inc., Cary, NC, USA).

Results

To verify the correlation between two quantitative variables, an analysis was performed through Pearson correlation coefficient (r), as we can see in ►**Table 4**. There was a strong

positive correlation when the following variables were correlated: subject's current age and age at hearing loss, current age and age when starting to use Has, and hearing loss onset age with the start of HA use. There was also a moderately negative relation between subject's age and mean hearing thresholds with CI after at least 12 months of use.

In the analysis of potentials N1, P2, N2 and P300, when correlated to the subject's gender, age, time of auditory deprivation, CI current (Hz), pulses per second (pps) and mean hearing thresholds with HAs, there was no significant value. However, P300 latency values in both phases, when analyzed and related to CI's current, show an increase in latency ($p = 0.0545$).

►**Figs. 1** and **2** show mean latency distributions for the N1 and P2 potentials (exogenous) and N2 and P300 (endogenous), respectively, in the different fixation positions of the electrodes (Cz and Fz) related to the two phases of the research, while ►**Figs. 3** and **4** show the mean distributions

Table 4 Correlation between audiological variables

Pearson correlation coefficient						
Parameter		Age at hearing loss	Auditory deprivation time	Age at HA fitting	Average HT with HA	Average HT with CI
Current age	Corr	0.6526[a]	0.0611	0.6450[a]	0.3062	−0.5912[a]
	p-value	0.0214[b]	0.8502	0.0235[b]	0.3329	0.0429[b]
Age at hearing loss	Corr	–	−0.2025	0.6816[a]	−0.1095	−0.5220
	p-value	–	0.6304	0.0146[b]	0.7346	0.0817
Auditory deprivation time	Corr	–	–	0.4778	0.4289	−0.0102
	p-value	–	–	0.1161	0.1641	0.9748
Age at HA fitting	Corr	–	–	–	0.1971	−0.5078
	p-value	–	–	–	0.5391	0.0919

Abbreviations: CI, cochlear implant; Corr, correlation; HA, hearing aid; HT, hearing threshold.
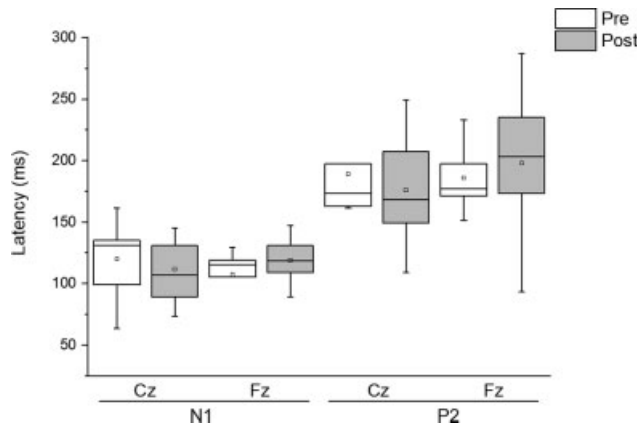[a]Corr $\geq$ 40%.
[b]$p < 0.05$.

Fig. 1 Distribution of latency measurements of the N1 and P2 waves in the pre- (using HA) and postphases (using CI), in the Cz and Fz electrode positions.
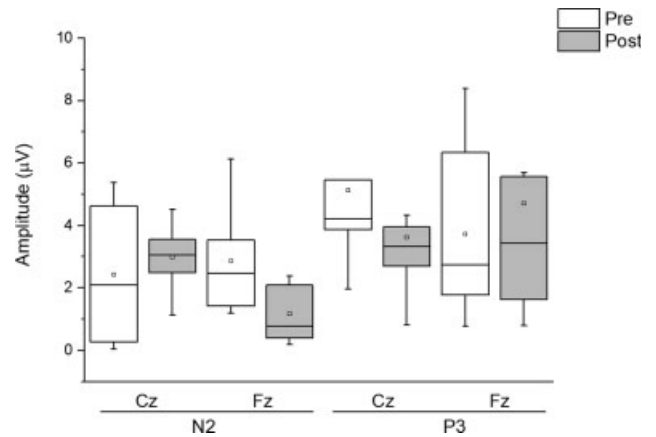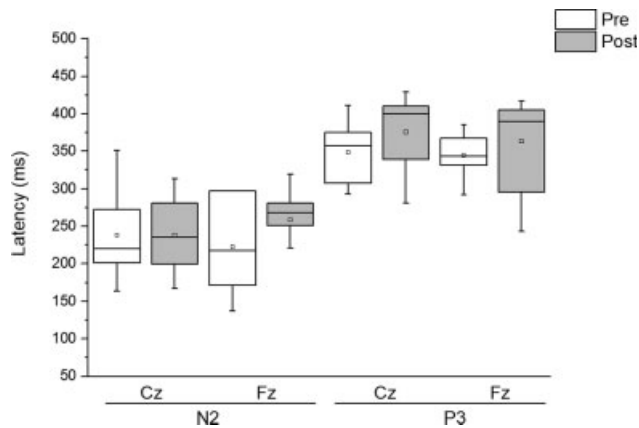

Fig. 2 Distribution of latency measurements of the N2 and P3 waves in the pre- (using HA) and postphases (using CI), in the Cz and Fz electrode positions.
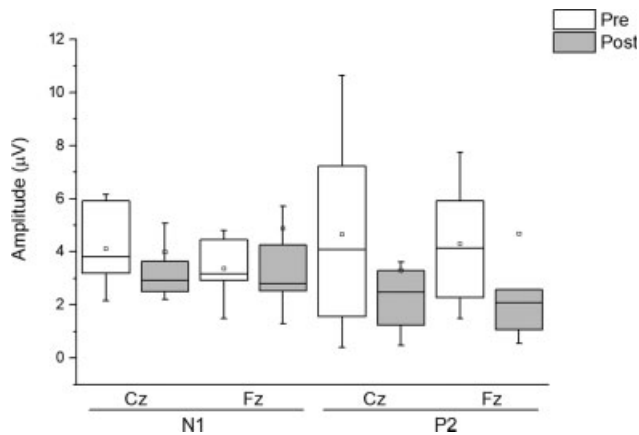

Fig. 3 Distribution of amplitude measurements of the N1 and P2 waves in the pre- (using HA) and postphases (using CI), in the Cz and Fz electrode positions.

of the amplitude. Due to the objective of this study, there was an emphasis on the P300 cognitive potential. Therefore, we can observe that P300 mean latency values at Cz and Fz increase in the CI phase. Amplitude levels decreased at Cz and increased at Fz during the transition from HA to CI.

Fig. 4 Distribution of amplitude measurements of the N2 and P3 waves in the pre- (using HA) and postphases (using CI), in the Cz and Fz electrode positions.
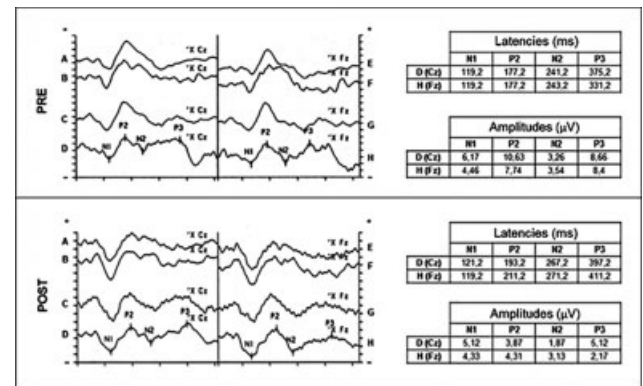
Fig. 5 Example of a record (with repetition) of the P300 test, about the present study, in the prephase (with HA) and post (with CI). Letters A, B E and F are frequent registers. Letters C, D, G and H are infrequent registers, with electrode position in Cz and Fz, respectively.

For both phases, wave morphology at Cz benefited the components' tracing (►**Fig. 5**).

It is important to note that during training, before starting to effectively register potentials, some individuals showed more difficulty to detect the rare stimulus in the HA phase, needing more training time. Still in this phase, a few subjects could not distinguish two rare stimuli when presented in sequence, with a reduced time gap, that is, two or more rare stimuli in a row. In the meantime, that did not occur when they were in the CI phase, since they started to promptly respond and identify the rare stimuli even when presented with short time gaps.

Regarding the behavioral task during the exam, in the HA phase, five subjects showed immediate response to the onset of rare stimuli, six showed late response to the onset of rare stimuli, and one showed an incompatible response, that is, he raised his index finger in the absence of a rare stimulus. During the CI phase, 11 subjects showed immediate response to the onset of rare stimuli and only 1 showed late response, which indicates an overall better performance in the CI phase.

Discussion

Cochlear implantation is known to be the best option for profound hearing loss,[16] as many studies show its effectiveness on the development of oral language and speech perception.[17–19] Cochlear implant centers establish as one of the audiological criteria for candidates that, although they have effectively experienced using HAs, they are not benefitted by such device. Besides, if mean hearing thresholds in free field with HAs reveal no access to speech sounds, that indicates that those patients are CI candidates.[20] With that being said, audiometry results from the first phase show correct indication of those subjects as CI candidates, with male predominance (58.33%), which is also seen in other studies[21,22] that show hearing loss is more frequent in male patients.

When correlating social and demographical variables related to hearing loss, it was verified that there is a strong positive correlation between the subject's current age and age at hearing loss (0.6526), current age and age when starting to use HAs (0.6450), and hearing loss onset age with age at the start of HA use (0.6816). Such result shows that this group of subjects received auditory stimulation through HAs, after hearing loss onset, and that is a crucial factor to consider for central auditory system activity maintenance. There was also a moderate negative correlation between the subject's age and mean hearing thresholds after at least 12 months of use (0.5912) (►**Table 4**). This finding is also addressed in the literature, describing that an increased time of CI use results in an improved hearing ability (identified by decreased hearing threshold results) and performance in patients with postlingual hearing loss. Even at CI activation, the ability to detect sounds is already noticeable and auditory recognition improves progressively, as well as speech comprehension, around 18 months after implantation.

We can verify that the data shown at ►**Table 1** reflect what has been happening in most audiological centers in Brazil, that is, individuals with early onset hearing loss (18.08 years old on average) waiting for a significant amount of time receive the intervention process (8.79 years of hearing deprivation on average) and an even bigger time when the time of HA adaptation is considered (26.58 years old on average).[23,24] Those findings are probably explained by the demand of patients within the observed age range, who now represent ∼ 50% of individuals who seek treatment and electronic hearing devices in the study's country (Brazil). This demand conflicts with financial difficulties of public health programs.

It was evident in this research that mean hearing thresholds were better with CI than with HA. The comparison shows difference between averages of 43.92 dB HL and a considerable difference in word recognition of 40.22%, equivalent to speech recognition improvement of over 10 words, showing there is a bigger benefit with the use of CIs (►**Table 2**).[20,25] One study from 2004[26] reported that, in the time between 6 and 12 months of CI use, some patients achieve their maximum hearing performance, while others keep evolving after 12 months.

Regarding etiology investigation, 50% of the subjects had an unknown cause of hearing loss and are under investigation, which agrees with previous researches.[21,22,26,27] Those studies indicate the need for genetic studies in cases of hearing loss with no apparent cause, so that we can get to a real etiological profile. Otosclerosis (16.67%) showed the highest frequency among other etiologies (mumps, bacterial meningitis, ototoxicity, and mechanical trauma), which were present only once each (8.33%). It was also noted that, when comparing average hearing thresholds with those of subjects with HAs and with CIs, only the subject with meningitis did not benefit from CIs and that is due to a reduction in the amount of spiral ganglion cells, which is a characteristic of the auditory system lesion caused by meningitis.[28,29]

At the time of data collection, there was an equal distribution of CI brands indicated to the patients, in a way that did not allow for a quantitative statistical comparison that could evaluate the association between the device brand and the subjects' responses to the tests.

Variables related to CI (►**Table 3**), such as number of channels, pulse rate by channel and current (Hz) did not present any significant difference when correlated to P300 amplitude and latency measurements, except for latency values correlated to HA and CI phases, which were increased. The latency of P300 does not depend on the physical characteristic of the acoustic stimulus, such as duration and intensity, but rather on proprieties related to the event, such as its probability, discrimination difficulty and stimulus novelty. Nonetheless, it is believed that there is a physiological P300 latency increase from the age of 15 years.[30–33] In this study, comparisons of latency measures were made between the same individuals in different situations, over a short period of less than a decade. Therefore, it is believed that variations are related to the use of the electronic device.

P300 mean latency values increased at Cz and Fz during the CI phase (►**Fig. 2**), which wasn't initially expected, since the auditory benefit provided by CIs, verified through behavioral evaluations, is bigger than the benefit provided by HAs. Even with that increase, it was observed that mean latency values are within normality, with 348.80 ms at Cz and 344.42 ms at Fz during the HA phase and 375.37 ms at Cz and 363.02 ms at Fz during the CI phase.[6]

This increase can reflect on the applied stimulus situation, which would activate more the parietal lobe region (P3b– 250–500 ms component). This region is activated by the "oddball" stimulus and is connected to the activity of performing a task while receiving a stimulus.[6] The P300 amplitude can be more related to the number of attention resources allocated to the stimulus and memory performance involved and represents brain's perception while receiving an important information.

The P300 amplitude can have a bigger association with the amount of attentional resources allocated to the stimulus and memory performance involved and represents brain's perception when receiving an important information. It is originated from different regions of the CANS that process different types of information, such as the frontal and central regions (P3a– 250–280 ms), and are related to the detection of stimulus novelty. The P300 latency reflects the time spent during stimulus cognitive processing and its amplitude is related to the amount of attention resources allocated during the stimulus.[34]

It is worth pointing out that some patients who had absent P300 responses in the HA phase started to show responses in the CI phase. A few studies also found an increase in P300 latency, justifying that the difficulty to discriminate stimuli can cause this latency increase, even if they respond correctly to the behavioral task.[9,35] One of those studies reports that patients who always presented better sound discrimination also presented better latency values, that is, shorter latencies.[9] Those findings suggest the possibility that direct electrical stimulation of the cochlea may not function as effectively as the auditory system does in conditions in which the cochlea is in its normal state, that is, not working simultaneously with an electric device.

When an individual is using HAs, a device that basically amplifies sound, the remaining cells are stimulated and the cochlea itself generates a nervous impulse, which is then transmitted to the CANS. This case is different from CI users, where there is an electricity transducer inserted in the cochlea to allow electric stimulation. This thought might explain latency delay at 12 months of CI use, and there is still the possibility that the cochlea needs more time to adjust to electrodes, which could bring different results in the future. Previous studies suggest there is information that codified sound delivered through CIs is different from the sound delivered by the normal cochlea, so it is likely that CI recipients' brains need highly charged auditory processing and, consequently, a higher effort during cognitive processing.[35]

In terms of amplitude, a decrease at Cz and an increase at Fz were observed from the HA phase to the CI phase. Amplitude values found were relatively low in both phases (HA phase = 5.13 µV at Cz and 3.71 µV at Fz; CI phase = 3.68 µV at Cz and 4.71 µV at Fz), and those values may be justified by the fact that the CI provides a lower discrimination field when compared with the cochlea itself. One study suggests P300's amplitude in CI patients is related to individual differences in their ability to discriminate, that is, patients with low discrimination capacity show lower amplitude levels.[7]

Although there was no significant difference between latency and amplitude results, it was noticeable that the wave morphology of frequent and rare stimuli during the test was more favorable to the tracing of the N1-P2-N2 complex and especially of the P300, in the rare register during the CI phase (►Figs. 1, 2, 3, and 4).

Considering the age factor, many studies suggest there is a variation of latency and amplitude measurements according to age; some studies show latency increase at around 1 to 2 ms/year, and amplitude decrease with an average rate of 0.2 µV/year.[36,37] In adults over 45 years old, latency increases 10 ms for each decade.[38] One hypothesis is that participants in this research were 46.5 years old on average, which is a factor to consider concerning latency increase. However, in this study, the results' comparison was obtained in a single-subject manner, which is considered the most stable situation and, therefore, it should not be a considerable variable. It is also worth highlighting that there was a time span of 12 months between tests, so the age variable alone could not interfere in the difference found, that is, the latency increase (►Fig. 2).[6,39,40]

Another factor that could affect the results could be the fact that this research was conducted on the same patient at different time intervals, which is not a strong consideration, since literature has shown that latency variations are small under those circumstances. One study found mean retesting values of 10.50 ms (Fz) and 15.25 ms for female gender and 6.00 ms (Fz) and 5.83 ms (Cz) for male gender.[37] Equivalent results were found in studies that demonstrated P300 latency measures test-retest reliability in normal adults[41,42] suggesting that those patterns, observed for a long time, can reflect on the habituation of certain processes in the central nervous system.[41]

Early responses are usually related to the presented stimulus' sensation, perception and discrimination, while delayed responses are usually related to cognition and memory.

The exogenous complex, N1, P2 and N2, in a qualitative analysis, also presented increased latency values, especially at the Fz position, with a 35.53 ms difference for N2, 11.80 ms difference for P2 and 12.00 ms difference for N1. Amplitude values, as described in the literature,[6] did not produce significant variations.

Statistical analysis showed that there was no relation between P300 and other variables; however, when related to latency values, in both phases, the result was $p = 0.0545$. Although this result shows no significance, the number of participants in this study could lead to a bias, so one hypothesis is that a larger sample could give the result a different tendency.

Once the aim of the evaluation was to identify the P300 wave, the fact that the response procedure (raising the index finger instead of mentally counting) was modified did not interfere in the type of response. Some studies have concluded that, when comparing long latency potentials evaluation procedures, with different instructions regarding the perception of rare stimuli, the complex N1, P2, N2 did not change, although P300 showed a slight modification, which is precocious in the lower cognitive complexity process.[12,43,44]

A longitudinal assessment is important so that CANS changes in adults with CIs can be evaluated in an extended period and compared with CANS development in adults with normal hearing. Thus, studies with larger samples and longer time of observation are necessary for a better understanding of hearing disorders.

Conclusion

Behavioral and electrophysiological assessments have contributed to a better understanding of hearing performance in CI users. The participants showed a remarkable improvement of their hearing thresholds after 12 months of CI use, except for the patient with meningitis. Mean P300 latency levels increased after 12 months of CI use at Cz and Fz, while mean amplitude levels decreased at Cz and increased at Fz. There was a moderate negative association between age and mean hearing thresholds with CIs.

Conflicts of Interest
The authors have no conflicts of interest to declare.

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