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Aspects Inherent To The Recovery Function Of The Auditory Nerve On The Speech Processing In Noise In Patients With Cochlear Implants

Wiemes, Gislaine R. M.; Goffi-Gomez, Maria Valéria; Muniz, Lilian; Sadowski, Tatiana; Marques, Isabela; Brito Neto, Rubens

Department Of Otorhinolaryngology - School Of Medicine, University Of São Paulo – FMUSP. Brazil
Department Of Speech-Language Pathology - Federal University Of Pernambuco – UFPE. Brazil

Abstract:
Background*: Cochlear Implant (CI) partially replaces the functions of the cochlea, converting sound energy into electrical signals, enabling electrical stimulation of the auditory nerve and transmission to the cerebral cortex. This study investigates auditory nerve Recovery Time (REC) and introduces the Frequency Following Response (FFR) with stimulus |da| as tools to assess auditory system integrity in CI users, particularly concerning speech perception in quiet and noise. This research aims to explore the correlation between REC, neural conduction in the brainstem, and speech recognition performance in CI users, contributing to the understanding and enhancement of this technology.*

Materials and Methods*: This was a prospective, cross-sectional, exploratory study, approved by the Institutional Review Board (IRB) of the hospital where the study was conducted. It involved 06 adults with postlingual deafness who underwent cochlear implant surgery, three women (mean age 67 years) and three men (mean age 70 years), three right ears and three left ears. Participants exhibited free-field auditory thresholds not exceeding 25dBHL from 250Hz to 6000Hz, with 70% speech recognition in quiet, stable electrode impedances, and present neural response (evoked compound action potential). Data collection included sentence recognition in quiet and noise, recovery time parameters involving absolute refractory period "T0," relative refractory period "tau", and saturation amplitude "A", assessed in three cochlear regions (apical electrode 16, medial electrode 11, and basal electrode 6). FFR included the investigation of wave "V" and valleys "A, C, D, E, F, and O".*

Results*: The results revealed moderate to strong positive and negative correlations between REC parameters, FFR latencies, and speech recognition in quiet and noise. Statistically significant correlations were particularly observed between REC ("T0, tau, and A"), in electrodes 11 and 6, and valleys "D and E".*

Conclusion: *This study demonstrated statistical correlation between auditory nerve recovery time and brainstem neural conduction for speech in CI users.*

Keywords: *Cochlear implant. Auditory Nerve Recovery Time (REC). Frequency Following Response (FFR), Speech Recognition in Silence and Noise.*

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I. Introduction

The cochlear implant (CI) is the treatment of choice for patients with severe or profound bilateral sensorineural hearing loss[1]. It consists of a surgically implantable device that converts sound into electrical signals[2] and sends them to the cerebral cortex for sound perception. The survival of a sufficient amount of neural structures in the auditory nerve allows this electrical stimulation to be transmitted to the cerebral cortex, providing essential auditory cues for the awareness of auditory perception and speech through electrical stimulation of the auditory nerve (AN) in patients with profound deafness[3].

The Frequency Following Response (FFR) with speech stimuli, formerly known as Auditory Brainstem Response (ABR) with speech stimuli, is a measure of synchronous neural activity evoked by sound that reveals the integrity of sound processing in the brain[4]. It is capable of representing the acoustic properties of the stimulus, meaning that the formants of speech are faithfully preserved in the brainstem response[5]. Changes in this response may indicate alterations in the perception of speech characteristics in patients with CI, where the speech stimulus is captured by the speech processor.

The FFR is an objective tool for assessing the integrity of the auditory system and assisting in predicting bimodal benefit in the non-implanted ear. This information can be valuable for clinical decision-making, especially in difficult-to-test populations[6]. The latency and amplitude measures of the brainstem responses with speech stimuli can provide insights into neural coding for speech sounds[7].

The REC provides information about the period that the fibers of the auditory nerve need to recover from the received stimulus and be ready to receive a new stimulus. The FFR, as a brainstem response, is capable of representing the formants of speech. We recognize the importance of intact neural conduction for speech recognition. Therefore, the objective of this research was to identify whether there is a correlation between the REC and neural conduction in the brainstem with speech recognition performance in CI users.

This study investigates the REC and introduces the FFR with stimulus |da| as tools to assess auditory system integrity in CI users, particularly concerning speech perception in quiet and noise. The aim of the research is to explore the correlation between REC, neural conduction in the brainstem, and speech recognition performance in CI users, contributing to the understanding and enhancement of this technology.

This is the first study, as far as we know, that demonstrates the feasibility of measuring FFR and analyzing the response with neural recovery time and speech recognition in silence and noise in individuals using CIs.

II. Methodology And Participants

This was a prospective, cross-sectional, exploratory study, approved by the Institutional Review Board (IRB) under the number CAAD 31313820.0.0000.0068. Patients who met the following selection and inclusion criteria were considered eligible and invited to participate: adult individuals of both sexes with postlingual onset deafness, who had received a CI with complete electrode insertion for over a year, and who showed neural responses intra and postoperatively on at least 3 electrodes; stable telemetry impedances (maximum variation of 10%) for at least 6 months and homogeneous, with free field hearing thresholds of up to 25dBHL at frequencies from 250 to 6000Hz, with 70% speech recognition in silence, individuals using the device for at least 8 hours daily, and without neurological alterations. Exclusion criteria included disagreement in marking between the two judges, presence of response in the FFR and absence in the REC or absence of response in the FFR and presence in the REC.

The study included 06 adult individuals who underwent CI surgery, with an average age of 68.5 years, three women and three men. All participants signed the Free and Informed Consent Form.

For the collection of REC, the default parameters of the Software Custom Sound EP 6.0 were used. The three electrodes chosen were 16 (apical), 11 (medial) and 6 (basal), each representing a region of the cochlea. The current level used is 10CL above t-NRT and the series recovery option is selected. REC uses 20 interval values between the stimulus discharge on the masking electrode and the stimulus discharge on the tested electrode (between 100 to 10000 μs), performing the test in one minute and 38 seconds. The interval between the masking and target stimulus (IPI) varies from 100 μs (100, 200, 300, 350, 400, 496, 614, 761, 944, 1170, 1450, 1797, 2227, 2759, 3420, 4239, 5253, 6510, 8069, 10000). The artifact cancellation technique used was the extraction of the masked response[8].

For the FFR test, the Intelligent Hearing System - IHS equipment was used. As impedance parameter, individual values of up to 5Kohms were admitted and impedance between the electrodes of 3 Kohms. To decrease stimulation artifacts, the System Connection interface - Bio-logic Systems Corp was used, and in an attempt to further reduce artifacts, a copper film was also used on the processor antenna. Surface electrodes positioned: negative polarity electrodes (-) in the region of the contralateral mastoid to the implanted side (M1 and M2); positive polarity electrode (+) placed in the forehead region, near the hairline (Fz) and the ground electrode in the lower front region (Fpz). The /da/ stimulus, 40ms, was selected considering its acoustic and electrophysiological properties[9]. The syllable /da/ has been most used because it is a universal syllable, present in most languages, and allows investigating how speech is encoded by the auditory system, being sensitive to changes in speech processing and temporal aspects[7,10]. The FFR elicited by /da/ stimulus produces a wave-shaped response, with seven peaks/valleys (V, A, C, D, E, F and O)[9,11,12].

The FFR collection was conducted in a free field with the patient seated at 0° azimuth, 1 meter away from the loudspeaker. The stimuli were transmitted acoustically in a free field at a presentation rate of 3.70 stimuli/s, with an intensity of 65 dBSPL for the syllable /da/, using alternating polarity. Two scans were averaged, each containing 2048 stimuli, resulting in the acquisition of two waveforms with a bandpass filter between 100-3000 Hz and a gain of 100 Hz, reproduced in a 71 ms window.

The traces obtained were superimposed and the presence and absolute values of waves "V, A, C, D, E, F and O" were marked. It is important to emphasize that the data were collected twice to ensure that the obtained waveforms demonstrated good reproducibility. Since this is an examination whose analysis is subjective, two speech therapists who study the FFR served as judges and individually marked the components of the waveforms.

The judges' markings were consistent. The analysis aimed to identify the onset portion for latency values (ms) of the first positive peak, "wave V," followed by the negative peak, "valley A," after the pre-stimulus period.

Subsequently, the following valleys (C, D, E, F, and O), which are negative peaks, were identified, and the latency of each trough was marked[9,11,13,14].

For the Sentence Recognition Test in silence and in noise[15], the patient was placed in an acoustic booth, where a list of sentences was presented, and they were instructed to repeat what they heard. After completion, the percentage was calculated based on the number of words repeated correctly. The speech recognition in silence was conducted with a recording at 65 dB, while the speech recognition in noise was also conducted with a recording at 65 dB and a Signal-to-Noise Ratio of +10 dB.

Statistical analysis

The data were organized in an Excel® spreadsheet and analyzed using the IBM SPSS Statistics v.28.0 software. To describe quantitative variables, average, standard deviation, median, minimum and maximum were presented. Categorical variables were described by absolute frequency and percentage. To evaluate the analysis between quantitative variables, the Spearman correlation coefficient (ρ (rho)) was used, indicating moderate or good correlation (coefficient ≥ 0.5 or ≤ -0.5). Coefficients with p-values < 0.05 indicate significant correlation.

Subsequent results were based on evaluating variables related to speech recognition, wave latency and neural recovery time. The latency was assessed by two judges, who were in agreement. The data from Judge 2 were considered for the analysis due to their greater experience.

III. Result

Six participants aged between 53 and 86 years, average age of 68.5 years, three women (average age of 67 years) and three men (average age of 70 years), three right ears and three left ears. All participants had more than one year of implantation and over 8 hours of daily use, as recorded by datalogging. Regarding etiology, all were post-lingual with progressive hearing loss. In table 1 it is possible to see the description of the sample studied.

Table 1 – Sample Description

Variable	Classification	N	%
Sex	Female	3	50,0%
	Male	3	50,0%
Implanted Ear	right ear (RE)	3	50,0%
	left ear (LE)	3	50,0%
Etiology	Otosclerosis	2	33,3%
	Idiopathic deafness	2	33,3%
	Genetic deafness	1	16,7%
	Deafness after TBI	1	16,7%

Legend: n = number of participants; TBI = Traumatic Brain Injury

Table 2 shows the average, standard deviation, median, minimum and maximum of each quantitative variable and absolute and percentage frequencies of each categorical variable.

Table 2 – Variables Age, Time of Deafness and Speech Recognition in Silence and Noise

Variable	n	Average	SD	Median	Minimum	Maximum
Age (years)	6	68,5	11,8	70	53	86
Time of deafness (years)	6	15,5	5,7	15	8	23
Time between CI and FFR (years)	6	5,6	2,5	5,7	2,2	9,7
Speech Recognition in Quiet Recording 65dB (%)	6	88,3	11,7	90	70	100
Speech Recognition in Noise +10 Recording 65dB (%)	6	68,3	33,1	75	30	100

Legend: n = number of participants; SD = standard deviation, CI = Cochlear implant; FFR = Frequency Following Response.

Our research shows (Table 3) the descriptive analysis of the latencies of the wave "V" and the valleys "A, C, D, E, F and O" in the FFR response for the six subjects who participated in the research. The average latencies were as follows: for wave "V" it was 13.0 ms, for the valleys "A" it was 14.7 ms, "C" was 26.4 ms, "D" was 31 .6 ms, "E" was 40.7 ms, "F" was 49.5 ms, and "O" was 56.6 ms.

Table 3 - Latencies of wave V and valleys A, C, D, E, F, and O in FFR (in ms)

Variable – Latency	n	Average	SD	Median	Minimum	Maximum
V	6	13,0	1,3	12,6	12	15,6
A	6	14,7	1,1	14,3	14	16,8
C	6	26,4	3,8	27,3	21	30,9
D	6	31,6	3,6	31,2	27	37,1
E	6	40,7	4,2	40	36	45,8
F	6	49,5	4	51,3	44	53,4
O	6	56,6	2,2	56,2	54	60

Legend: n = number of participants; SD = standard deviation.

Table 4 presents the descriptive analysis of the research on the absolute refractory period (T0), relative refractory period (tau), and saturation amplitude (A), known as recovery time (REC), for the different regions of the cochlea. These regions are represented by electrodes 16, 11 and 6.

Table 4 – Comparison of descriptive analysis of recovery time data - REC for electrodes 16 (apical), 11 (medial) and 6 (basal)

Variable		n	Average	SD	Median	Minimum	Maximum
REC 16	T0	6	675	180	609	532	1011
	tau	6	699	417	634	215	1408
	A	6	28	17	21	15	58
REC 11	T0	6	588	156	571	343	782
	tau	6	1004	349	919	655	1439
	A	6	31	21	22	18	72
REC 6	T0	6	508	101	545	349	600
	tau	6	1002	299	853	764	1497
	A	6	20	7	17	14	33

Legend: n = number of participants; SD = standard deviation; REC = *Recovery Time*

A positive correlation, moderate to good (ρ (rho) = 0.65), was observed between the variables for speech recognition in silence, tested with a recording at 65 dB, and the latency of valley "O", which corresponds to the end of the response. Similarly, a positive correlation was noted between the variables for speech recognition in silence and the absolute refractory period (T0) for electrodes 11 (ρ (rho) = 0.79) and 6 (ρ (rho) = 0.50).

On the other hand, between the variables of speech recognition in silence and the absolute refractory period (T0) of electrode 16 (ρ (rho) = -0.62), there was a negative, moderate or good correlation. Exactly the same positive correlation was observed between the variables for speech recognition in noise, with a signal/noise ratio of +10 dB, test performed with recording at 65 dB, and the latency of the “O” valley (ρ (rho) = 0.53).

Again, a positive correlation can be observed between the variables for speech recognition in noise and the absolute refractory period (T0) of electrodes 11 (ρ (rho) = 0.77) and 6 (ρ (rho) = 0.50). On the other hand, between the variables for speech recognition in noise and the absolute refractory period (T0) of electrode 16 (ρ (rho) = -0.68), there was a negative correlation.

The same correlations found with the “V” wave and neural recovery time were also found with the latency of the “A” valley, presented consecutively. A positive correlation exists between the latencies of the “V and A” waves and the relative refractory period (tau) of electrode 16 (ρ (rho) = 0.78 and ρ (rho) = 0.78). Additionally, there was a positive correlation between the latencies of the “V and A” waves with the saturation amplitude (A) in electrodes 16 (ρ (rho) = 0.41 and ρ (rho) = 0.56) and 6 (ρ (rho) = 0.63 and ρ (rho) = 0.63). A negative correlation was observed between the absolute latencies of the “V and A” waves and the absolute refractory period (T0) of electrodes 16 (ρ (rho) = -0.67 and ρ (rho) = -0.52) and 6 (ρ (rho) = -0.64 and ρ (rho) = -0.64).

There was a negative correlation between the latencies of the “V and A” waves and the relative refractory period (tau) of electrode 6 (ρ (rho) = -0.49 and ρ (rho) = -0.52). Regarding the “C” valley, which corresponds to the transition region between consonants and vowels, we found a positive correlation with the saturation amplitude (A) in electrode 11 (ρ (rho) = 0.77) and a negative correlation between the “C” valley and the saturation amplitude (A) in electrode 6 (ρ (rho) = -0.77).

In Table 5 we observed a statistically significant and positive correlation between the latency of the “D” valley and the “A” saturation amplitude in electrode 11 (medial), with a value of $p<0.05$ ($p=0.008$). And a statistically significant and negative correlation, with $p<0.05$ ($p=0.015$) between the valley “D” and the relative refractory period (tau) of electrode 6 (basal).

Table 5. Correlations of the latency of valley “D” with absolute (T0) and relative (tau) recovery period, and the amplitude of the saturation level (A)

Variables	N	Coef de correl de Spearman	p
Latency D x REC T0 16	6	-0,03	0,957
Latency D x REC tau 16	6	-0,06	0,913
Latency D x REC A16	6	0,35	0,499
Latency D x REC T0 11	6	0,06	0,913
Latency D x REC tau 11	6	0,26	0,618
Latency D x REC A11	6	0,93	0,008
Latency D x REC T0 6	6	-0,32	0,538
Latency D x REC tau 6	6	-0,90	0,015
Latency D x REC A6	6	-0,39	0,447

Legend: n = number of participants; p = p-value or probability of significance

The positive and significant correlation between the latency of the “D” valley and the amplitude of the saturation (A) in electrode 11 (medial), therefore, the greater the amplitude in the middle segment of the cochlea, the greater the latency of the “D” valley. Likewise, it shows a strong and significant negative correlation of the relative refractory period in the basal region (electrode 6). In other words, the shorter the relative refractory period, or the lower the nerve density for high frequencies[16], the greater the latency of the “D” valley.

In table 6 was possible to observed a good correlation, with p=0,042 (p<0,05), between the latency of the “E” valley and the relative refractory period (tau) on electrode 11 (medial), and a good correlation, also with p=0,042 (p<0,05), between the latency of the valley “E” and the absolute refractory period (T0) at electrode 6 (basal).

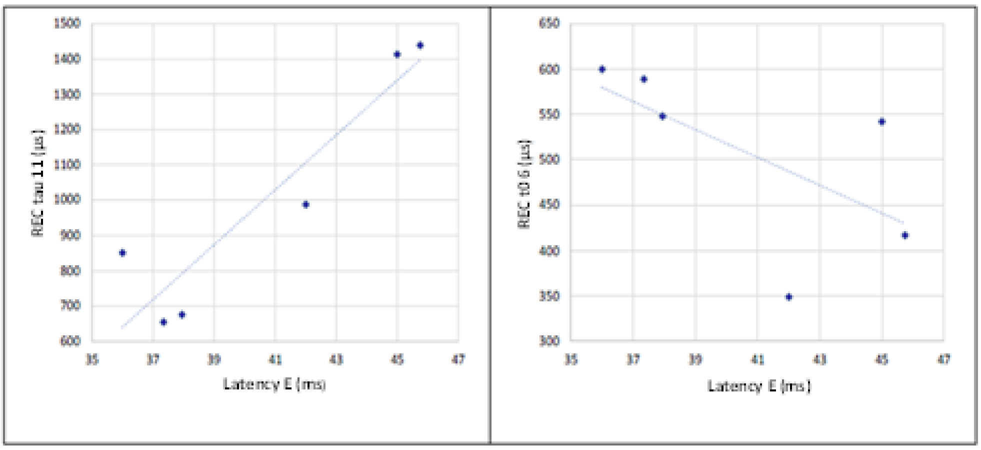
Table 6. Correlations of the latency of “E” valley with absolute (T0) and relative (tau) recovery period, and the amplitude of the saturation level (A)

Variables	n	Coef de correl de Spearman	p
Latency E x REC T0 16	6	0,03	0,957
Latency E x REC tau 16	6	0,09	0,872
Latency E x REC A16	6	0,54	0,266
Latency E x REC T0 11	6	-0,49	0,329
Latency E x REC tau 11	6	0,83	0,042
Latency E x REC A11	6	0,37	0,468
Latency E x REC T0 6	6	-0,83	0,042
Latency E x REC tau 6	6	-0,49	0,329
Latency E x REC A6	6	-0,09	0,868

Legend: n = number of participants; p = p-value or probability of significance

We can say that there is a positive and significant correlation between the latency of the “E” valley and the relative refractory period (tau) in electrode 11 (medial), therefore, the higher the tau in the middle segment of the cochlea, the higher the latency of the “E” valley. Likewise, a negative and significant correlation of the absolute refractory period in the basal region (electrode 6). In other words, the lower the t0, that is, the lower the nerve density for high frequencies[16], the higher the latency of the “E” valley.

Figure 1 - Scatter plot by subject showing the "Relative Refractory Period" (tau) of Electrode 11 and the "Absolute Refractory Period" (T0) of Electrode 6.



In Figure 1, significant direct correlations are presented, represented in scatter plots, according to the values of the two variables: the latency of the "E" trough and the relative refractory period with electrode 11. A significant inverse correlation was observed between the latency of the "E" trough and the absolute refractory period with electrode 6.

For the "F" trough, there is a positive correlation with electrode 16 in the relative refractory period (tau) (ρ (rho) = 0.66) and in the saturation amplitude (A) (ρ (rho) = 0.60). Additionally, a negative correlation was found in the absolute refractory period with REC at electrode 16 (ρ (rho) = -0.77) and electrode 6 (ρ (rho) = -0.54).

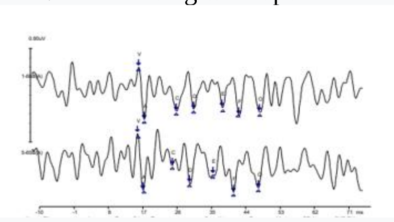
With the "O" trough, there is a positive correlation with the saturation amplitude "A" at electrode 11 (ρ (rho) = 0.66) and a negative correlation with the absolute refractory period at electrode 16 (ρ (rho) = -0.60) and the relative refractory period at electrode 6 (ρ (rho) = -0.54).

In our analysis, we found a positive correlation between REC and speech recognition in both silence and noise. We also found a moderate to good correlation between the latencies of the FFR and REC.

With these results, we observed a stronger correlation between the FFR and REC, and a weaker correlation between speech recognition in silence and noise with REC or with the FFR.

Measuring FFR in CI users proved to be a big challenge, as the generated artifact was substantial, and not all individuals, even with identical parameters. In figure 2 we can see a plot of the FFR response.

Figure 2: FFR Tracing with Speech Processor



IV. Discussion

The value of this work is demonstrated by the lack of data in the literature on FFR in implanted patients and the fact that we were able to conduct the assessment despite the difficulties in obtaining responses from these patients.

A significant challenge was the lack of research on FFR in individuals with CI, which made comparison with the literature difficult. Initially, we searched for the best parameters to collect the response, since the parameters used in individuals with normal hearing resulted in many noise artifacts and not all individuals, even using the same parameters, were able to produce a response due to differences in artifact duration among CI users[17].

We were able to reduce the radiofrequency interference caused by the processor antenna using the System Connection interface – Bio-logic Systems Corp. However, it was not possible to obtain a response in the FFR for all tested individuals. We also tried using a copper film on the processor, but it did not always work, and we believe that this did not have relevance concerning the results obtained.

Venancio et al. (2022), with the aim of characterizing the acquisition parameters, analysis, and results of the FFR examination in CI users, analyzed six studies that met the inclusion criteria and observed that variations in acquisition parameters were common, with analyses predominantly in the time domain. CI users showed differences in FFR results when compared to individuals with normal hearing, considering the existing literature. They concluded that there is no standardization of an acquisition and analysis protocol for FFR in CI users, and the results are at high risk of bias. Therefore, for the conduct of this study, we sought in literature which parameters would provide us with better responses for FFR analysis.

We believed that, due to the proximity of the response location, both the “V” wave and the “A” trough could be related to or influenced by the recovery time. We observed that these were the ones that showed the highest positive or negative correlation, whether moderate or good, especially in the apical and basal regions. This supports our suspicion that the REC may influence the first wave of the FFR; however, it did not show statistical significance.

When we reviewed all the analyses of the moderate or good correlation coefficients, whether positive or negative, we found some type of correlation in almost all the analyzed variables (speech recognition in silence, speech in noise, REC, and FFR). However, statistical significance was only stronger ($p<0.05$) when relating the latency of the FFR, troughs “D” and “E” with REC (T0, tau, and A).

We observed that, in our research, we also found the troughs “D”, “E”, and “F” separated by approximately 8 ms, as shown in studies in individuals with normal hearing[11,19] and with implanted individuals[20.] The analysis of the latencies of the “V” wave and the troughs “A, C, D, E, F, and O” in the FFR for the 6 adults who participated in the study, revealed similar averages than those reported by Jarollahi et al. (2020) in children (table 7).

Table 7. Latencies of wave “V” and valleys “A, C, D, E, F, and O” in FFR (in ms)

Latency (in ms)	Wiemes et al. (N = 6)	SD	Jarollahi et al. (2020) N = 20
V	13.00	1.3	11.92
A	14.7	1.1	13.43
C	26.4	3.8	24.32
D	31.6	3.6	27.71
E	40.7	4.2	36.52
F	49.5	4	45.64
O	56.6	2.2	54.16

Legend: n = number of participants; SD = standard deviation;

Carvalho et al. (2022) concluded in their study that there was a statistically significant difference in the REC when comparing electrodes stimulating different regions of the cochlea. They suggest that this difference may be related to populations of stimulated neurons or to a different number of residual neurons due to the pathophysiology of hearing loss, or also to the effect of the modiolus embracing the electrode. In our study, we observed that the region of the cochlea that showed the highest moderate to good correlation, both positive and negative, in the measurement of REC was the apical region.

We observed in our results that both for speech recognition in silence and in noise, there was a moderate to good positive correlation with the absolute refractory period (T0). This means that the absolute refractory period directly or indirectly influences speech recognition in silence and in noise. The same direct relationship was observed regarding speech in silence and in noise and the latency of the “O” wave, suggesting that the “O” wave may be influenced by speech recognition in silence or in noise. Therefore, we believe that the higher the percentage of speech recognition in silence and in noise, the greater the temporal resolution, favoring speech processing in CI users.

With these results, we observed a greater correlation between the FFR and REC, and a lower correlation between speech recognition in silence and in noise with REC or with the FFR. Therefore, we dare to say that our results support the idea that, with prolonged recovery time, there will be more responsive fibers favoring speech processing in CI users. Few studies have been conducted on the FFR in CI users, and this research is of great importance as it demonstrated that it is possible to perform the FFR in individuals with CI.

The central auditory system has the capacity to change with plasticity, even in adulthood. This capacity for change contributes to the clinical improvements observed in speech perception in CI users[22]. Knowing how the stimulus propagates in the auditory pathway stimulated by the CI allows us to understand the difficulties and how to improve the programming and/or auditory rehabilitation of the implanted individual. We believe that the mappings of implanted patients could be improved through the association of research on objective measures conducted via neural recovery function and the neural response through the FFR.

The study of the FFR in cochlear implant (CI) users is very promising. Studies with a larger number of participants and homogeneous populations are essential to confirm the changes found, as well as new studies testing different parameters, examining the FFR response with competitive noise in implanted patients and others, with the aim of enhancing the electrophysiological response with the CI and better assessing the relationship between speech understanding in silence and in noise.

The weak point of our research was the limited number of participants, because the artifact generated made collection difficult and we know that it may have affected the result, however it is important to emphasize that new research should also emerge in order to find a way to isolate the artifact generated by the processor magnet.

V. Conclusion

It was possible to identify a correlation between the auditory nerve recovery time (REC) and neural conduction in the brainstem for speech in cochlear implant (CI) users. We found a statistically significant correlation between the latencies of the Frequency Following Response (FFR) and the REC in CI users. There was a moderate to good correlation between the latencies of the FFR and performance on the speech test in silence and in noise in CI users, as well as a moderate to good correlation between the REC and speech performance in silence and in noise in CI users.

References

[1] NATEGHIFARD, Kayvan Et Al. Cone Beam CT For Perioperative Imaging In Hearing Preservation Cochlear Implantation–A Human Cadaveric Study. Journal Of Otolaryngology-Head & Neck Surgery, V. 48, N. 1, P. 1-8, 2019.

[2] WIDMANN, Gerlig Et Al. Pre-And Post-Operative Imaging Of Cochlear Implants: A Pictorial Review. Insights Into Imaging, V. 11, N. 1, P. 93, 2020.

[3] FALLON, J. B.; IRVINE, D. R. F.; SHEPFERD, R. K. Cochlear Implants And Brain Plasticity. National Institutes Of Health, Australia, V. 238, N.1-2, P. 110-117, 2008.

[4] KRAUS, Nina; ANDERSON, Samira; WHITE-SCHWOCH, Travis. The Frequency-Following Response: A Window Into Human Communication. Springer International Publishing, 2017.

[5] HORNICKEL, Jane Et Al. Auditory Brainstem Measures Predict Reading And Speech-In-Noise Perception In School-Aged Children. Behavioural Brain Research, V. 216, N. 2, P. 597-605, 2011.

[6] KESSLER, David M. Et Al. Frequency Following Response And Speech Recognition Benefit For Combining A Cochlear Implant And Contralateral Hearing Aid. Trends In Hearing, V. 24, P. 2331216520902001, 2020.

[7] ROCHA, Caroline Nunes Et Al. Potencial Evocado Auditivo De Tronco Encefálico Com Estímulo De Fala. Pró-Fono Revista De Atualização Científica, V. 22, P. 479-484, 2010.

[8] MILLER, Charles A.; ABBAS, Paul J.; BROWN, Carolyn J. An Improved Method Of Reducing Stimulus Artifact In The Electrically Evoked Whole-Nerve Potential. Ear And Hearing, V. 21, N. 4, P. 280-290, 2000.

[9] SKOE, Erika; KRAUS, Nina. Auditory Brainstem Response To Complex Sounds: A Tutorial. Ear And Hearing, V. 31, N. 3, P. 302, 2010.

[10] HODGE, Sarah E. Et Al. Forward Masking Of The Speech-Evoked Auditory Brainstem Response. Otology & Neurotology: Official Publication Of The American Otological Society, American Neurotology Society [And] European Academy Of Otology And Neurotology, V. 39, N. 2, P. 150, 2018.

[11] RUSSO, Nicole Et Al. Brainstem Responses To Speech Syllables. Clinical Neurophysiology, V. 115, N. 9, P. 2021-2030, 2004.

[12] SANFINS, Milaine Dominici; SKARZYNSKI, Piotr H.; COLELLA-SANTOS, Maria Francisca. Speech-Evoked Brainstem Response. Adv Clin Audiol, V. 9, 2017.

[13] SANFINS, Milaine Dominici Et Al. Speech-Evoked Brainstem Response In Normal Adolescent And Children Speakers Of Brazilian Portuguese. International Journal Of Pediatric Otorhinolaryngology, V. 90, P. 12-19, 2016.

[14] JOHNSON, Krista L.; NICOL, Trent G.; KRAUS, Nina. Brain Stem Response To Speech: A Biological Marker Of Auditory Processing. Ear And Hearing, V. 26, N. 5, P. 424-434, 2005.

[15] COSTA, Maristela Julio; SANTOS, Sinéia Neujahr Dos. Desenvolvimento Do Teste Listas De Sentenças Dicóticas Em Português Brasileiro. Audiology-Communication Research, V. 21, 2016.

[16] BOTROS, Andrew; PSARROS, Colleen. Neural Response Telemetry Reconsidered: II. The Influence Of Neural Population On The ECAP Recovery Function And Refractoriness. Ear And Hearing, V. 31, N. 3, P. 380-391, 2010.

[17] GRANSIER, Robin Et Al. Frequency Following Responses And Rate Change Complexes In Cochlear Implant Users. Hearing Research, V. 404, P. 108200, 2021.

[18] VENÂNCIO, Leonardo Gleygson Angelo Et Al. Frequency-Following Response (FFR) Em Usuários De Implante Coclear: Uma Revisão Sistemática Dos Parâmetros De Aquisição, Análise E Resultados. In: Codas. Sociedade Brasileira De Fonoaudiologia, 2022. P. E20210116.

[19] KRIZMAN, Jennifer; KRAUS, Nina. Analyzing The FFR: A Tutorial For Decoding The Richness Of Auditory Function. Hearing Research, V. 382, P. 107779, 2019.

[20] JAROLLAHI, Farnoush Et Al. Sound-Field Speech Evoked Auditory Brainstem Response In Cochlear-Implant Recipients.Journal Of Audiology & Otology, V. 24, N. 2, P. 71, 2020.

[21] CARVALHO, Bettina Et Al. Neural Recovery Function Of The Auditory Nerve In Cochlear Implant Surgery: Comparison Between Different Regions Of The Cochlea. Cochlear Implants International, V. 23, N. 4, P. 232-240, 2022.

[22] FALLON, J. B.; IRVINE, D. R. F.; SHEPFERD, R. K. Cochlear Implants And Brain Plasticity. National Institutes Of Health, Australia, V. 238, N.1-2, P. 110-117, 2008.