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Association between Behavioral and Electrophysiological Measurement of Young Implanted Recipients on their Speech Processing

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Abstract

Aim: There are two aims of this study:

1. Analyzing of auditory behavioral and electrophysiological speech responses of young implanted recipients.

2. Association between behavioral and electrophysiological responses of people with cochlear implant.

Method: Twenty one subjects of both genders (13 male and 8 female), aged from 18 to 30 years (mean age 24.71 ± 3.92) were enrolled in this study. These participants used unilateral cochlear implant for at least 5 years. Fifteen participants had prelingual, 6 had postlingual deafness. They all used oral language for communication. For the quantitative measurement, event related P300 potentials were used to assess speech perception of 21 unilaterally implanted users in silent and noise conditions. The P300 responses were measured with speech stimuli at 70 dBnHL in silent and noisy conditions and the latencies of P300 waves were analyzed. For the matrix test, the speech discrimination scores of the participants were estimated in noisy conditions.

Results: The quantitative based results showed that P300 responses were observed in 10 out of the 20 CI users in silent condition, but in 5 of these patients the P300 responses disappeared when tested in noise. In the quiet condition, 50% of the respondents had received a P300 response in the noisy environment, while 50% of the respondents did not have it. No statistical differences were observed for P300 latencies of participants in silent and noise conditions (p=0.0603). Also, no significant correlation were found between the P300 responses of the cochlear implant users and their Matrix test scores for both test conditions (p=0.391 and p=0.188).

Conclusion: Both subjective and objective methods can be used to evaluate auditory discrimination. Objective electrophysiological methods such as P3 wave have been widely used in cochlear-implant users, highlighting the difficulties subjects experience in perceiving speech in noise. Even with good educational level of implanted people, their speech understanding ability was not enough. Implanted people have difficulty for both speech perception and discrimination ability for both quiet and noisy conditions.

Keywords: Unilateral cochlear implant; Speech discrimination; Auditory evoked potentials; P300

Introduction

Understanding speech in noisy conditions is often difficult for people with a hearing impairment. In the presence of background noise, people with hearing deficits have greater disadvantages in understanding speech, than people with normal hearing [1,2]. People with severe/profound hearing loss are known to get little to no benefit with the use of hearing aids in those cases; cochlear implants are an alternative way, which can provide a high speech perception. More recent data from Fetterman and Domico [3] have verified the difficulty of cochlear implant users to comprehend speech in background noise. Carhart and Tillman [1] suggested that speech understanding of patients with hearing loss in background noise is important in clinical condition. A speech perception test has

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Table 1: Demographic information of participants. N/A indicates that participant s/he didn't remember the information.

No	Age (years)	Onset of deafness (pre/ postlingual)	Age at conventional hearing aid (years)	Age at implantation (years)	Onset of special education (years)	Duration of special education (years)	Side of ear/Type of implant	WDS in quiet condition (%)
1	20	prelingual	1	6	1.5	15	R/Med-El	80
2	20	prelingual	2	2.5	2.5	5	R/Cochlear	80
3	19	prelingual	3	6	3.5	12	R/Cochlear	80
4	20	postlingual	7	13	-	-	L/Cochlear	80
5	25	prelingual	2	7	2	-	R/Cochlear	72
6	22	prelingual	2.5	6	5	3	R/Cochlear	96
7	29	prelingual	2	16	7	3	R/Cochlear	72
8	20	postlingual	7	11	-	-	L/Med-El	72
9	26	prelingual	1	13	1	1	R/Cochlear	80
10	30	postlingual	N/A	6	-	-	L/Cochlear	80
11	20	prelingual	1.5	8	1.5	4	R/Cochlear	84
12	29	postlingual	6	17	-	-	R/Med-El	76
13	24	prelingual	N/A	3.5	3.5	10	R/Cochlear	76
14	26	prelingual	2	10	3	11	R/Cochlear	68
15	23	prelingual	1	10	8	10	R/Cochlear	68
16	25	prelingual	1	5	2	12	R/Cochlear	84
17	28	postlingual	5	13	-	-	R/Cochlear	80
18	30	postlingual	6	26	-	-	R/Cochlear	76
19	24	prelingual	-	3	-	-	R/Cochlear	80
20	30	prelingual	1.5	27	27	7	R/Cochlear	76
21	30	prelingual	5	21	-	-	R/Med-El	9

been common procedure to assess behaviorally speech understanding ability of people with hearing deficits. Commonly used clinical tests for speech perception in noise include: The Hearing in Noise Test (HINT), the Words in Noise Test (WIN), the Quick Speech in Noise Test (Quick SIN) and the Matrix sentence tests. Also, auditory evoked cortical potentials can also be used for objective evaluation of speech comprehension for people with hearing loss.

The Matrix test was developed by Hagerman in 1982 for the Swedish language [4]. The test is available for other languages such as Turkish [5], British English [6], Danish, Dutch French, Russian, Spanish, German and Polish. All versions of the Matrix test have the same psychometric properties thus they are easily comparable [7]. The Matrix test can be applied adaptive and non-adaptive in various SNRs. Speech Reception Threshold (SRT) scores, for both quiet and noise conditions, can easily be determined by the Matrix test. Sentences are syntactically fixed but semantically unpredictable [1]. The words which generate randomly these sentences derive from a 50 word inventory. The test duration is approximately 2 min to 4 min, for an open set format, where the participants are asked to repeat the words that they have understood. In a closed session format, the participants select the words they understood showed on a screen [2].

The use of Cortical Auditory Evoked Potentials (CAEP) allows the functional evaluation of the auditory cortex and of the structures responsible for the cognitive processing of auditory stimuli. The CAEP is characterized by 5 principal components: The P1, N1, and P2 are called exogenous components and they derive information from the primary auditory cortex; the N2 and P3 components provide information about higher cognitive processes [3]. P1 is an important marker of central auditory pathway maturation in hearing impaired children. N1 is the encoding of the beginning of a stimulus at the auditory cortex level [4,5]. P3 is a cortical evoked potential and occurs approximately 300 ms following stimulus onset. Data in the literature show that cochlear implant users are characterized by longer P3 latencies and diminished amplitudes [6,7]. This suggests that the P3 component is a good indicator of cortical sensory processing providing accurate and useful information on the acoustic phonological processing of data. The P3 has been tested with both people with cochlear implant and hearing aid. Now, it is gradually being included in clinical settings; however, more studies with P3 in young adult population with cochlear implant are necessary to show its applicability [6-8]. Hopefully, the results obtained in this study can help us to assess CI recipients' processing function together with behavioral and electrophysiological measurements as sensitive indicators.

Thus, there are two aims of this study:

1. Analyzing of auditory behavioral and electrophysiological responses of young implanted recipients for speech understanding in noise.

2. Evaluating the association between behavioral and electrophysiological responses of people with young cochlear implants.

Materials and Methods

Ethical approval of study

This study was approved by the Ethics Committee of Institution Review Board under Protocol No 09.2018.409. The participants read and signed the Terms of Free and Informed Consent prior to any clinical session.

Demographic information about the participants

Twenty-one subjects of both genders (13 male and 8 female), aged from 18 to 30 years (mean age 24.71 ± 3.92) were enrolled in this study. These participants used unilateral a cochlear implant for at least 5 years. The subjects demonstrated no other physical or psychological disability. Fifteen participants had prelingual, 6 had postlingual deafness and used the oral language for communication. In terms of health-care, they were followed by the same Audiology clinic. All participants had a university degree. Subjects with a Word Discrimination Score (WDS) lower than 60% with CI were not included in the study. The demographic data of the hearing loss group are summarized in Table 1.

Measurements

The participants were evaluated by the following 3 testing conditions, in order to assess their speech intelligibility and discrimination ability in noise: (i) by a free-field measurement using their cochlear implant; (ii) by a Matrix test; and (iii) by a CAEP P3 measurement. Patients using a hearing aid (6/21) were requested to remove it during the measurements. Also, all tests were conducted on the same day in a sound-treated double-walled room (IAC Acoustics, Sound Seal, IL, USA). Additional details on the testing procedures are presented in the section below.

Free field sound measurement: Prior to the administration of the Turkish Matrix test, the hearing threshold levels of the CI users were measured in a free field. Speech Reception Thresholds (SRT) were estimated by using Turkish polysyllabic words, while Speech Discrimination Scores (SDS) were estimated in quiet by a list of 25 monosyllabic words at 40 dB SL. The Word Discrimination Scores (WDS) of the participants are shown in Table 1.

Matrix test: For the Matrix test, a MADSEN Astera Audiometer (Otometrics, Natus Medical, Denmark) and a Denox speaker system were used, inside a sound-proof booth. All stimuli were presented through a JBL Control One loudspeaker (JBL, Harman International, USA) that was positioned at 0° azimuth and 0° elevation at a 1-m distance from the subjects. Participants were instructed to repeat the words they understood and the tester marked the correct answers using a dedicated software program (Oldenburg Measurement Application). All the stage conditions, speech and noise levels, were equal for all participants. Non-adaptive parameters were used during the measurements. Intelligibility scores of participants were evaluated as percentage value. Table 2 shows the test parameters of the Matrix test.

P3 test: Patients sat in a chair and electrodes were attached according to International Electrode System standard IES 10-20. The active electrode was placed on Cz and the reference electrode on the left mastoid process. The ground electrode was placed on Fz. All subjects were instructed to look at a fixed point, one meter in front of them and to count silently all the rare stimuli of each run. The subjects were tested with their speech processors. Cortical auditory evoked potentials for frequent and rare stimuli were averaged simultaneously, but separately. A total of 300 stimuli (20% rare and 80% frequent) were used to generate the P3 component. The actual number of target stimuli presented was slightly above 50. The event-related Potential (P3) was identified at the rare stimulus recording from 230 ms to 500 ms after stimulus onset. The P2 potential was measured at 125 ms to 230 ms during data collection, P1, P2 and P3 responses of participants were identified and analyzed for both quiet and noisy conditions. A MADSEN Astera Audiometer (Otometrics, Natus Medical, Denmark) and a Denox speaker system were used, inside a sound-proof booth. All stimuli were presented through a JBL Control One loudspeaker (JBL, Harman International, USA) that was positioned at 0° azimuth and 0° elevation at a 1-m distance from the subjects. Table 3 summarizes the P3 protocol parameters.

Table 2: Test parameters of Matrix test.

Response mode	Open format
Signal to noise ratio (S/N)	15 dB
Speech level	70 dB SPL
Intensity of noise	55 dB
SNR	15 dB
Total of stimulus	50 words/20 test lists
Level control	Nonadaptative free field measurement
Test & noise mode	Standart
Measurement/fixed level	Measurement in noise
Transducer	Free field- (Speaker 1)
Test options	SRT
Results	Intelligibility (%)

Table 3: Test parameters of P300.

Intensity of stimulus	70 dBnHL
The artifact rejection level	± 100 µV
Band-pass filters of EEG	0.1 to 30 Hz
Frequnt stimulus	/da/
Target stimulus	/ba/
The actual number of target stimuli	Above 50
Presentation rate of stimulus	1.1 stimuli for per second
Total of stimulus	300 (20% rare and 80% frequent)
SNR	15 dB
Intensity of noise	55 dB

Statistical analysis

Descriptive values of the quantitative data were calculated as mean ± standard deviation, median [IQR] and percentage (%). The distribution of normality of the quantitative data was examined by the Shapiro Wilk test. The data were found to be normally distributed. Non-parametric tests were used when the number of participants was low. The Spearman Rho Correlation analysis was used to evaluate the relationships. The measurements of the same participants under two different conditions were examined by Wilcoxon Sign Test and Mc Nemar test for the same patients' responses under different conditions. Statistical significance was taken as $p<0.05$. Statistical analysis of the data was performed by IBM SPSS Statistics 22 (IBM SPSS, Turkey).

Results

There were 21 participants in the study but one subject presented P3 responses with many artifacts so the corresponding data were not included in the analyses. For the Matrix test, all 21 responses were included in the study.

The P3 responses from the 20 subjects, in both quiet and noisy

Table 4: P300 responses of the 20 patients in quiet and noise conditions.

	P300 responses in quiet condition	P300 responses in noise condition
Number of subjects with visible responses	10	5

*total number of participants are 20

Table 5: P300 Responses of participants for two conditions.

		P3/noisy condition		
		No N (%)	Yes N (%)	P
P3/ Quiet condition	No response	10 (100)	0 (0)	0.0603[a]
	Response	5 (50)	5 (50)	

[a]: Mc Nemar test

conditions, are shown in Table 4. For 10 subjects it was possible to obtain a P3 response in quiet, but this number was lowered to 5 subjects, when testing in noise conditions.

Table 5 summarizes the number of P3 responses obtained in quiet and noisy conditions. P3 responses for quiet condition were present for 10 patients, but P3 responses for noisy condition were obtained for 5 patients. 100% of the patients who had no P3 response in a quiet environment could not get a response in a noisy environment as well. In the quiet condition, 50% of the respondents had a response in the noisy environment, while 50% of the respondents did not have the same responses. No statistically significant differences were observed between two conditions (p=0.0603).

Table 6 shows the descriptive values of the latencies related to the P3 response. In quiet, the P300 mean latencies were 309.6 ± 40.8 ms. In noise, the mean P3 latencies was delayed to 321.4 ± 36.6 ms.

The latencies of the P3 responses from the implanted group were compared in the quiet and noisy conditions. No statistically significant differences were observed (p=0.225). The data are summarized in Table 7.

Table 8 presents the descriptive values for Matrix scores of cochlear implanted people. According to this, the minimum scores of people were 9, maximum scores were 99, the mean scores of people were 76(%), and median were 81.

In Table 9, comparison of the matrix score of the patients according to the groups was presented. According to the table, it was calculated that the patients' matrix scores were significantly lower than the control group in terms of their medians (p=0.001).

In Table 10, the correlation between P3 responses of people with hearing impairment and their Matrix scores were examined. It was found that there were no significant correlation between them (p=0.391 and p=0.188).

Table 9: Correlation of P300 responses and matrix scores of people with cochlear implant.

		Matrix scores
P3 responses for noisy condition	r	0,700
	p	0,188
	N	5

Discussion

This study focused on the relationship between speech perception in noise and P3 characteristics for young cochlear implant recipients. To assess a subject's comprehension in noise the Matrix test was used for behavioral examination and P3 recordings were used to evaluate the auditory discrimination capacity of the participants as electrophysiologically.

In this study, 10 of participants presented P3 responses in quiet, while the other 10 did not show any P3 responses. Also, the mean P3 latencies of implanted recipients was delayed when noise was added but there was no statistically significant difference between two conditions. This corroborates with the data in the literature that P3 responses were absent for 'poor speech performances' of implanted people and P3 responses were get from 'good speech performances' of implanted people and control group [7,8]. Also, this finding has supported with the other study in literature that in cochlear-implant bearers, the P300 wave was identified only in those with good auditory performance [9].

Several factors can contribute to variable CI outcomes such as the duration of the hearing loss and the onset age for the transition from severe to profound HL [8]. The implantation age and the cross-modal reorganization may be a factor that may explain some of the variability for speech understanding ability of the implanted adults [10,11]. The range of speech performance among individual CI users varies widely. It is assumed that performance with an implant is strongly associated with the auditory processing abilities of the individual and the integrity of the central auditory pathways from the auditory nerve to the cortex [12]. Indeed, performance is correlated with duration of deafness, age at onset of deafness (pre, peri, or post-lingual), etiology of deafness, and the number of remaining spiral ganglion cells [8]. In this study, there were 3 participants who were implanted before 3.5 years from 21participants. For the others who were implanted after 3.5 years. They were implanted lately, so it was too late to get sensory input for our participants in this study. According to this finding, long term sensory deprivation and late implantation were thought to be the main causes for the lack of P3 responses in people with hearing loss [8].

Table 6: Descriptive values of participants in terms of P300 responses for two conditions.

Number (n) of participants	(P300 Latency ± SD) of participants in quiet condition	(P300 Latency ± SD) of participants in noisy condition
Cochlear implanted group(n=20)	309.6 ± 40.8 ms	321.4 ± 36.6 ms

Table 7: Comparison of the P300 latency values, in subjects presenting hearing impairment for quiet and noisy conditions.

	N	Mean	Median	Std.deviation	Minimum	Maximum	p
P3 (quiet)	5	299,20	309,00	28,244	244	369	0.225[a]
P3 (noisy)	5	321,40	322,00	36,569	277	376	

[a]: Wilcoxon Signed Rank test

Table 8: Descriptive values for Matrix scores of implanted group.

	Mean	Median	Std. Deviation	Minimum	Maximum
People with hearing impairment (N=21)	76,000	81,000	24,59065	9,00	99,00

Another factor which could affect speech perception ability of hearing impaired people is auditory training with hearing aids/cochlear implants. Data in the literature show that auditory rehabilitation can enhance and restore the auditory perceptual skills which are essential for spoken language and, as a consequence, it may also help to ameliorate the central management of other cognitive resources associated with speech and hearing processes [13]. In our study, participants started to use hearing aids and cochlear implants lately; they also received the rehabilitation/special education lately. There were 7 prelingual implanted participants who got auditory training with their cochlear implant before 3.5 years. 6 implanted participants got auditory training with cochlear implant after 3.5 years and 8 participants didnt get auditory training in the past. Therefore, it was thought that starting auditory training lately could be reason for speech performances of participants in this study.

Furthermore, the incidence of the P3 response, obtained from 10 subjects, in quiet conditions was reduced to 5 when noise was added. This finding was consistent with the literature that speech discrimination of hearing impaired people was significantly affected in terms of noise. Peters, Moore, and Baer explained this finding as normal hearing system uses spectral and the temporal cues in the noisy environment for speech discrimination [14]. Depending on the decrease of audibility in the noisy environment, people with hearing loss cannot properly use these cues and have difficulty understanding speech-especially as hearing loss increases. There were also many studies which were consistent with this finding that noise affected P3 response for segmental speech processing (in terms of phonemic contrasts such as /ba/vs/da/ and different signal-to-noise ratios for implanted people [15,16]. Accordingly, noise caused significant increases in P3 latency and decrease in P3 amplitude for behaviorally discriminable speech stimuli, which were accompanied with increases in behavioral reaction time and reductions in accuracy. As supported with this finding, many researchers explained prolonged P3 response for hearing impaired people as in addition to reduced audibility and auditory deprivation [8], impaired suprathreshold spectrotemporal processing skills or decrease in cognitive ability, such as impaired auditory attention, memory, or processing speed, may contribute to reduced performance in noise [17-19]. For our study, when we found that latencies of participants were delayed for noise condition as consistent with the literature but there were no statistically significant correlation between P3 latencies of implanted people for quiet and noise conditions. This finding can be explained by our small sample size.

Moreover, to evaluate speech perception of the implanted subjects as behaviorally, the Matrix test was used in this study. The mean score of speech perception in noisy conditions was 76% ± 24.5 for implanted recipients. According to data from Taşdemir [20], people with normal hearing scores' were 99.19 (SD: 0.911) for Matrix test. 16 subjects' (6 male and 10 female; mean age is 21.69 ± 3.57) age and educational level where same with our study. Also, they were all had a university degree and presented a normal hearing profile (i.e. hearing threshold ≤ 20 dB HL from 0.25 kHz to 8 kHz). That's why we compared our Matrix test score with their participants. So, when we compare the results of implanted people's speech perception score with their normal hearing age matched groups were lower than normal hearing people in noise. This finding was supported with the other study in the literature that Armstrong, Pegg, James et al. [21] evaluated speech perception ability of adult implanted people and they found that phonemic auditory discrimination ability of implanted people in noisy condition was lower than in quiet condition. Furthermore, Alnıaçık and Akdaş [22] also found that speech reception scores of implanted people in noise with omnidirectional mode were statistically lower than those obtained in quiet condition. They explained that noise affect speech perception of CI recipients on their both peripheral and central hearing system negatively. In a similar way, Martin et al. [23] explained this situation as noise basically reduce the audibility of the desired signal to be heard and induces elevation in the hearing thresholds by masking it. This change in threshold makes speech understanding decrease [24].

Also, when we examine the association between speech perception and discrimination ability of implanted recipients in noise condition, we found no statistically significant correlation between speech perception ability and the P3 response of participants. However, in another study, Bennett et al. [25] found significant correlation between sentence intelligibility scores and the P3 peak latency measures for detecting the phonemic (/ba/ *vs.* /da/). They stated implanted people with good speech ability show shorter P3 latency. This was supported with the other studies which stated that there is significant correlation between speech scores of implanted people with CAEP measurements. For example, Micco et al. [7] stated that P3 responses to speech phonemes in a group of 'good' CI users were similar to those of normal hearing listeners. Also, Kileny recorded P3 responses of implanted children and found that P3 occurrence depended upon discrimination of the stimulus. A poor performing subject did not have a P3 (indicator of discrimination) but did have N1-P2 (an indicator of detection) [26]. Also, Kileny et al. [27] investigated the relationship between MMN and P3 (recorded using a tonal frequency contrast) and speech scores in implanted children. Significant correlations were found between MMN latency, P3 latency and amplitude, and sentence scores with higher speech scores associated with shorter latencies and greater MMN and P3 amplitudes. As an explanation for this result, we thought that small number of sample size was reason of non-significant correlation of our participants' P3 results and Matrix test. We evaluated and compared 5 participants' performances on noisy conditions with Matrix test and P3 in this study.

In conclusion, both subjective and objective methods can be used to evaluate auditory discrimination. Objective electrophysiological methods such as P3 wave have been widely used in cochlear-implant users, highlighting the difficulties subjects experience in perceiving speech in noise. Even with good educational level of implanted people, their speech understanding ability was not enough. Implanted people have difficulty for both speech perception and discrimination ability for both quiet and noisy conditions. They went university with their normal hearing age matched and got class in crowded context. They are using cochlear implant unilaterally. It can be so difficult to understand the class with their unilateral implant. If they started to use cochlear implant bilaterally within critical period with auditory training/special education, we thought that implanted people speech score would be improved.

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