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Relationship Between Auditory Cortical Responses and Language Development Levels in Pediatric Cochlear Implant Recipients in a Noisy Environment and a Quiet Environment

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ABSTRACT

Background: Congenital hearing loss (hearing loss present at birth) is one of the most prevalent chronic conditions in children. Children with hearing loss have deficiencies in their speech and language development in the future, depending on the degree of hearing loss. Cochlear implantation is a very common treatment modality for congenital hearing loss. The aim of this study was to investigate the correlation between auditory cortical responses and language development levels of cochlear implant users in noisy and quiet environments.

Methods: Thirty patients who underwent cochlear implantation were included in the study. The patients' responses to auditory cortical stimuli first included the /m/, /t/, /g/ phonemes, their language and speech development levels (Test of Early Language Development-3), first in a quiet environment, and then in a noisy environment, with a suitable speaker system at a distance of 1 m. evaluated and the data were statistically analyzed.

Results: It was observed that the wave morphologies of the phonemes m/,/t/, and /g/ deteriorated, their amplitude values decreased, and their latencies were prolonged in the noisy environment (S/N = +10dB) compared to the auditory cortical responses in the quiet environment ($P < .01$). A significant difference was observed between the receptive-expressive language equivalent values to the patients' peers in the quiet and noisy environments ($P < .01$).

Conclusion: The language performance of the cochlear implant patients in the noisy environment was considerably lower than their language performance in the quiet environment. Patients with cochlear implants; it is recommended to organize their education and social life together with the family, taking into account their performance in quiet/noisy environments.

Keywords: Auditory cortical responses, cochlear implant, expressive language, receptive language, signal-to-noise responses

Introduction

Congenital hearing loss (hearing loss present at birth) is one of the most prevalent chronic conditions in children. Hearing loss is known as the most common disease among congenital diseases in the world. While there are publications reporting the incidence of congenital hearing loss as 0.1%-0.6%,[1,2] more recent publications have reported the estimated prevalence of permanent bilateral hearing loss as 1.33 per 1000 live births, primarily due to the more active use of newborn screening systems.[3] The prevalence of congenital hearing loss in Türkiye was previously found to be 0.26%.[4]

Children with hearing loss experience many deficits in the future. One of the most important of these deficits is in speech and language development. These children with hearing loss have slower receptive and expressive language skills compared to children with normal hearing. For example, word perception performance in receptive language was found to be lower in children with hearing loss than that of children with normal

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hearing.[5] There are many factors that affect speech and language development in people with hearing loss. These include the degree of hearing loss, the time period in which the hearing loss occurs, and the time period in which the hearing loss is diagnosed.[6] Medical treatment, hearing aids, and surgery are different methods that are used in the treatment of hearing loss.

A cochlear implant is a device designed for hearing in patients with bilateral severe and profound sensorineural hearing loss who do not benefit from hearing aids.[7] There are, however, differences in speech discrimination skills and language and speech production after cochlear implantation. Variables such as the timing of implantation, the duration of implant use, the rehabilitation received by the user, and the presence of additional disabilities are highlighted as factors that affect cochlear implant performance.[8,9] One of the parameters used to evaluate the performance of cochlear implants involves the responses of the auditory cortex. This evaluation parameter includes the potentials that occur in the cortical region, the highest level of the auditory pathways, indicating the threshold of sound perception.[10]

The aim of this study was to investigate the correlation between auditory cortical responses and language development levels of cochlear implant users in noisy and quiet environments.

Methods

The study included 22 patients who had undergone cochlear implant surgery at the Department of Otolaryngology, Faculty of Medicine Hospital, İstanbul Cerrahpaşa University and were followed up at the Audiology Clinic between 2016 and 2017, as well as 8 patients who had received cochlear implants at the Otolaryngology Clinic of İnönü University Medical Center and were followed up at the Audiology Clinic.

Inclusion Criteria

- Only cochlear implant users who were selected according to the following criteria were included in the study:
- Being between 3 and 8 years of age,
- Absence of a middle ear pathology,
- Patients who underwent cochlear implantation in the prelingual period with the diagnosis of congenital hearing loss,
- Use of hearing aids for at least 3-6 months in the preoperative period,
- Use of cochlear implants for at least 1 year,
- Having an average pure-tone threshold of 35 dB or higher (those who achieved an average of 35 dB or better in the free-field in the frequency range 125-8000 Hz were allowed to participate in the next phase) in free-field behavioral audiometry,
- Having regular special education,
- Having regular cochlear implant checks and settings,
- Having no additional disability (e.g., mental retardation, neurological problems).

Exclusion Criteria

- Being younger than 3 years old or older than 8 years old,
- Patients with cholesteatoma and/or a middle ear pathology,
- Patients who underwent cochlear implantation in the postlingual period with the diagnosis of acquired hearing loss,
- Less than 1 year of cochlear implant use,
- Average pure-tone threshold worse than 35 dB in free-field behavioral audiometry,
- Patients who have not received regular special education,
- Patients who do not have regular cochlear implant checks and adjustments,
- Patients with missing data.

Audiological Terms

- dB: The decibel (dB) is a logarithmic, dimensionless unit commonly used for sound intensity, denoting the ratio to a given reference power or quantity level.
- dB A: It is a sound evaluation unit that emphasizes the middle and high frequencies to which the human ear is most sensitive.
- dB SPL (Sound pressure level): SPL is a measure of the sound pressure usually detected by microphones and is usually expressed in units of dB SPL. SPL starts at 0 dB SPL, which is the lowest sound level that the human ear can hear. Normal speech level is about 60 dB SPL.
- dB HL (Hearing Level): Hearing loss is measured in decibel hearing level (or dB HL). This is the softest level a person can hear.
- dB nHL: is the sound intensity term used for non-tonal stimuli.

Audiological Evaluation

Impedance Measurement Evaluation

Middle ear acoustic impedance measurement AT235 clinical tympanometry device was performed. Impedance measurement used in acoustic immittance testing is an objective test method that provides rapid and non-invasive evaluation of middle ear cells. The insert earphone is placed in the outer ear canal and the volume between the eardrum and the earphone is measured. Thus, pressure in the middle ear, stapedius reflexes, and tension of the eardrum are measured.

Free-Field Test

Hearing thresholds were evaluated using the AC40 true hybrid clinical audiometer. This device allows us to evaluate frequencies between 125 Hz and 8000 Hz. In the first stage, audiometric measurements of the participants' frequencies between 125 Hz and 8000 Hz were made. Hearing thresholds of 35 dB and above (500-4000 Hz) on average were included in the second stage. In the second phase, the auditory evoked late latency test was administered to the participants for their cortical responses.

Auditory Cortical Responses

The auditory cortical responses of the patients involved in the study were measured using a cortical auditory-evoked potential (CAEP) analyzer (HearLab) from the National Acoustic Laboratories (NAL) of Australia (Frye Electronics, Inc; Tigard, Oregon, USA).

The latency of cortical waves to the stimulus delivered with a stimulus intensity of 75 dB SPL was measured. Verbal (m, t, g) stimuli were used in the process. The latency values and

amplitudes of the cortical waves obtained as a result of the verbal stimuli /m/, /t/, /g/ (meaning "mmmm'," "te," "ge," and/or "ga" in Turkish) were recorded. The phonemes /m, t, g/ were used as verbal stimuli. Turkish pronunciations of the related phonemes are embedded in the CAEP analyzer (HearLab). Each verbal stimulus (in the ACA module of HEARLab, there are 3 different speech stimuli, /m/ (200-500 Hz), which carries low frequency information, /g/ (800-1600 Hz), which carries mid frequency information, and /t/ (2000-8000 Hz), which carries high frequency information, with dominant energy spectrum in different frequency bands) was recorded through electrodes placed on the patient. Amplitude values are expressed in microvolts (μV), while latency values are expressed in milliseconds (ms). The decibel (dB) is a logarithmic, dimensionless unit commonly used for sound intensity, denoting the ratio to a given reference power or quantity level. There are 2 evaluation parameters, HL and SPL. The dB A scale is a weighting used to evaluate the frequency range in which speech frequencies are used.

First, at a distance of 1 m from the loudspeaker system in a quiet environment, from an angle of zero degrees, a stimulus intensity of 75 dB SPL was measured. Then, the same noise stimulus was measured at a distance of 1 m from the loudspeaker system, from an angle of 180 degrees, with 65 dB SPL cocktail party noise (S/N = +10dB). The noise stimulus had the format of broadband noise known as cocktail party. The diagram showing the execution of late latency tests in the noisy and quiet environments is shown in Figure 1. In both cases, the latency and amplitudes of the phonemes /m/, /t/, /g/ were measured, and the results were compared. Some images of electrophysiological waves in the quiet and noisy environments of one of the late latency tests are shown in Figure 2.

Language Development Assessment

The Test of Early Language Development in Turkish language (TEDİL) was used to assess language development. TEDİL is the Turkish version of the TELD-3 (Test of Early Language Development) that was developed by Hresko, Reid, and Hammill[11]was used to measure receptive and expressive language development. TEDİL was adapted by Topbaş and Güven in 2013.[12] The normative data of TEDİL were collected from a heterogeneous group of 1200 normally developing children aged between 18 months and 8 years. It examines receptive and expressive language and can be used to identify language delay and language disorders and plan interventions accordingly. The test comprises verbal instructions given to the child, stimulus objects, or pictures to which the child is asked to respond. In this study, TEDİL-3 scores are presented as standard scores. The combined spoken language standard score is compiled from receptive and expressive subtest points. Scoring ranges from 35 to 165 points. A score between 85 and 115 points is considered normal. The scoring system is shown in Table 1.[13]

The results of the test can be used for purposes such as diagnosing children with language deficits at an early age, identifying the deficient and sufficient aspects of their language development, obtaining information about language development processes, and conducting studies for these purposes. First, the speaker system was placed in the silent booth at a distance of 1 m from the zero-degree angle at a speech level of 75 dB, and the participant was given a speech development

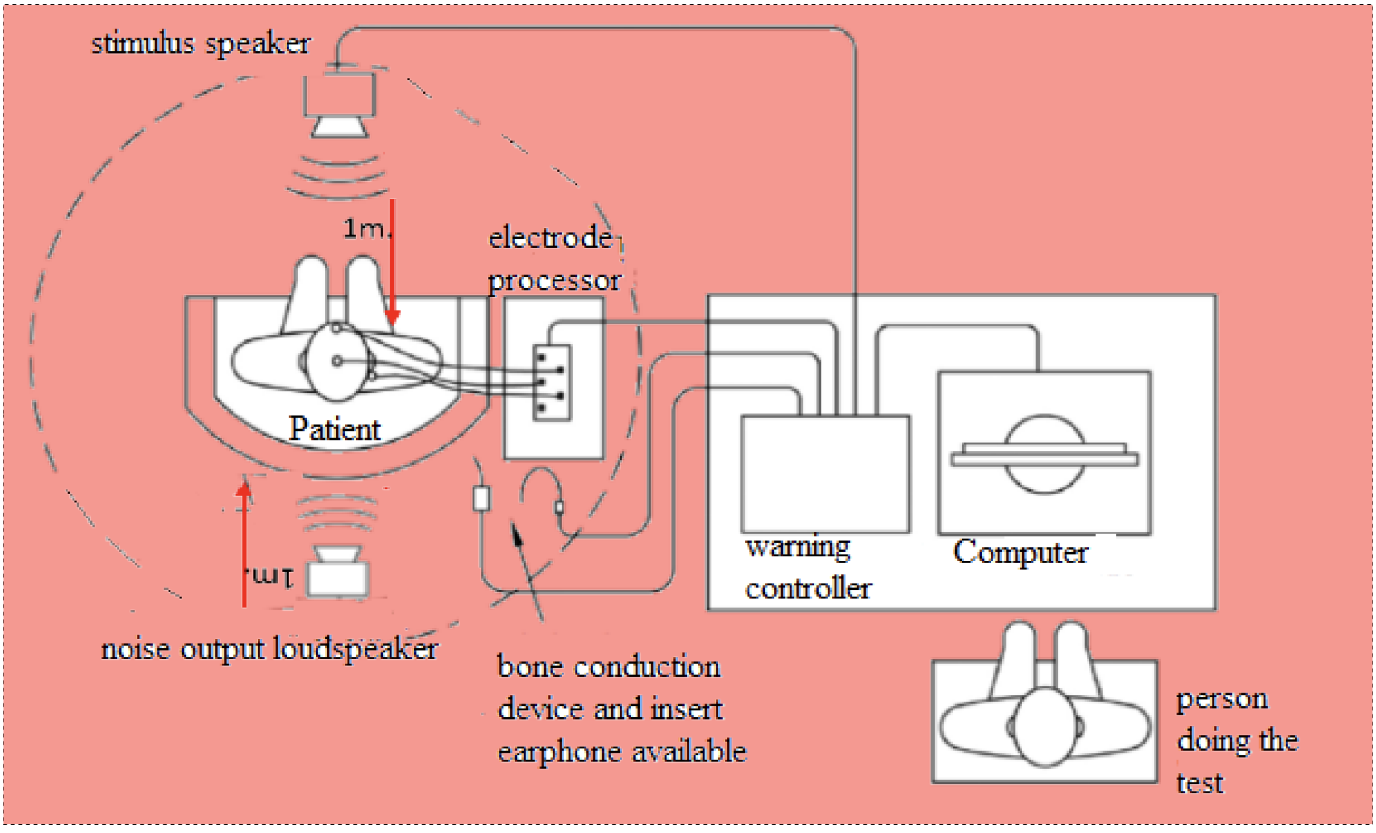

Figure 1. Scheme of late latency tests in noisy and quiet environments.

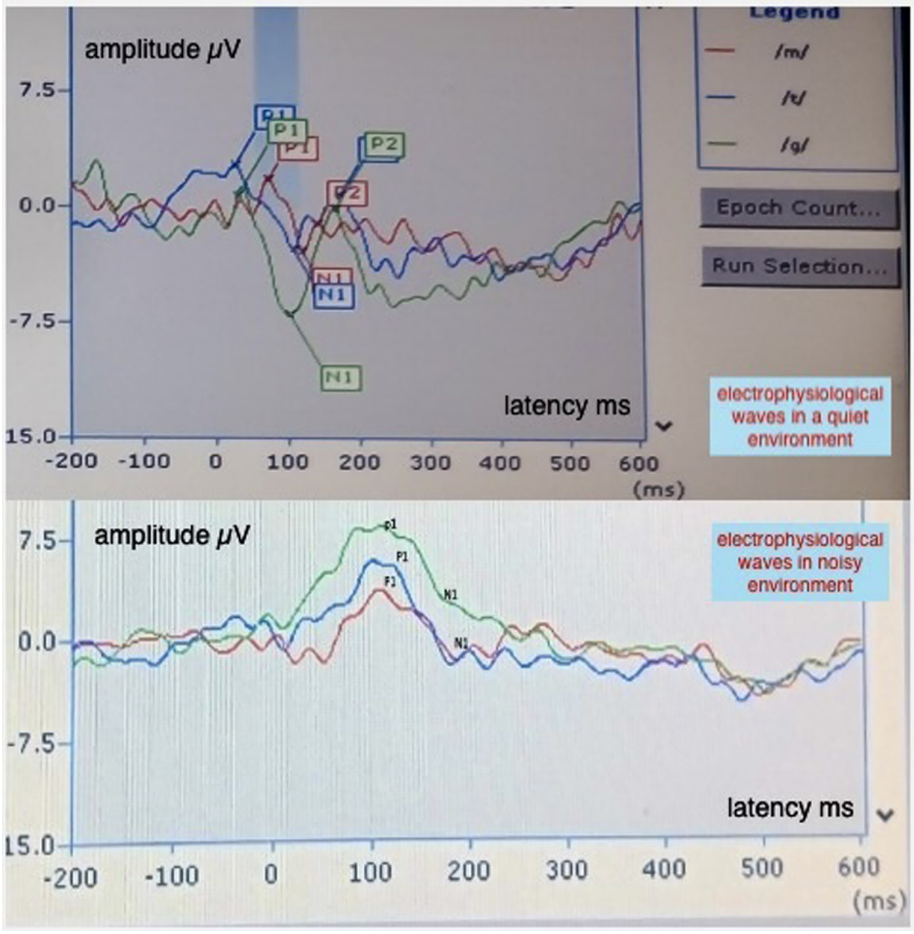

Figure 2. Sample images of electrophysiological waves in quiet and noisy environments in one of the late latency tests.

test of form A or B. Then, the speech sound was tested in the same position with 65 dB of cocktail party noise (S/N = +10dB) at an angle of 180 degrees. The results of speech development in the 2 conditions were compared (Figure 1).

Statistical Analysis

The statistical analyses of the study were performed using the IBM SPSS21 (SPSS Inc.; Chicago, IL, USA) software. The analyses included mean and standard deviation values, the Wilcoxon test, and *t*-tests.

The Shapiro–Wilk test was used to examine whether the data were normally distributed. The data are summarized with mean, minimum, and maximum values. The paired-samples Wilcoxon test and Friedman test were used for comparisons. The Conover method was used for multiple comparisons after the Friedman test. The significance level was assumed to be 0.05 for all tests.

Table 1. TEDL-3 Scoring System

Combined Spoken Language Standard Score	
131-165	Very good
121-130	Good
111-120	Above average
90-110	Average
80-89	Below average
70-79	Weak/poor
35-69	Very poor
131-165	Very good

Ethics Committee Approval

Our study was conducted in accordance with the principles of the Declaration of Helsinki, and "informed consent" was obtained from the parents of the children participating in the study. This study was conducted with the written approval of the Ethics Committee of the Hospital of the Faculty of Medicine of İstanbul Cerrahpaşa University (Approval no: 355069, Date: October 04, 2016).

Results

Thirty patients with audiological follow-ups were included in the study. The mean age of the patients was 69.86 ± 10.5 months. Their mean duration of cochlear implant use was 46.6 ± 10.09 months. The sample included 17 female patients and 13 male patients (Table 2).

In the comparisons of the chronological ages of the patients to their equivalent ages corresponding to their receptive and expressive language TELD-3 scores in the quiet and noisy environments, a statistically significant difference was found ($P < .01$) (Table 3). The receptive and expressive language performance levels of the patients were found to be lower than

Table 2. Demographic Characteristics of the Patients and Their Durations of Cochlear Implant Use

	Mean Age (Months)		Implant Usage Period (Months)	
Sex $n_{(n1+2)}$:30)	Male (n_1:13)	Female (n_2:17)	Male (n_1:13)	Female (n_2:17)
Minimum	52	47	27	34
Maximum	86	91	60	66
Mean ± SD	69.9 ± 8.5	70.3 ± 12.4	45.3 ± 11.2	48 ± 8.5

those of their peers. The performance levels of the patients were categorized and evaluated in 12-month periods. No significant difference was found between the measurements of the receptive-expressive language age equivalents of the children aged "47-59" months made in the quiet and noisy environments. Significant differences were found between the receptive-expressive language age equivalent measurements of the children aged "60-71, 72-83 and 84-95" months in the quiet and noisy environments. The chronological ages/months of the patients and their receptive-expressive language age/month equivalents and TEDIL-3 performances in the quiet and noisy environments (S/N ratio= +10dB) are given in Table 4 and Figure 3.

In the comparisons of the results of the auditory cortical responses of the patients, there were statistically significant differences between the measurements made in the quiet environment and those made in the noisy environment in terms of the phonemes /m/, /t/, /g/, as well as the P1 latencies and amplitudes ($P < .01$). To determine the distribution of these differences by month, age was categorized at 12-month intervals, and the statistical analysis was performed again. No significant difference was found between the amplitudes and latencies of the phonemes "P1m, P1t, P1g" in the measurements in the quiet environment and those in the noisy environment in the children aged "47-59 or 84-95" months. Significant differences were observed in children aged "60-71 or 72-83" months ($P < .01$) (Table 5). The results of the comparisons of amplitude values, latency values, and receptive-expressive language equivalent age development levels for the P1m, P1t, and P1g components in the quiet and noisy (S/N ratio = +10dB) environments based on the birth ages/months of the patients are shown in Figure 4. Having only 3 or 4 participants in some subgroups is insufficient for statistical analysis, but the results are valuable in that they will be one of the issues to be considered for future studies and constitute a good example for the further examination of these relatively small groups.

In both quiet-environment and noisy-environment measurements, statistically significant differences were found between the chronological ages of the patients and their age-equivalent receptive and expressive language development levels measured based on their TELD-3 scores. That is, the receptive and expressive language equivalent ages of all cochlear implant patients measured during the study were behind their chronological ages.

When language development was assessed in the quiet and a noisy environment, the verbal language performance of almost all participants decreased when the noise factor was present. Among amplitude values of the phonemes /m/, /t/, /g/, in the auditory-evoked cortical responses of participants in both environments, the ones measured in the quiet environment

Table 3. Equivalent Age Data of the Receptive and Expressive Language Scores in the Quiet and Noisy Environments

	The Test Environment	Number of Patients	Chronological Ages of Patients (Months) Mean ± SD	Equivalent Ages (months) of Patients Corresponding to TELD-3 Scores Mean ± SD	*P*
Receptive language age/month	Quiet	30	69.9 ± 10.5	62 ± 12.1	<.01**
	Noisy	30	69.9 ± 10.5	53 ± 10.4	
Expressive language age/month	Quiet	30	69.9 ± 10.5	56.5 ± 9.1	<.01**
	Noisy	30	69.9 ± 10.5	51.5 ± 7.6	

P < .05** was considered statistically significant.

Table 4. Receptive Language, Expressive Language, and Verbal Language Performance Levels of the Patients

	Chronological Ages of Patients (Months)	Equivalent Ages (Months) of Patients Corresponding to TELD-3 scores		
		Quiet	Noisy	
	Mean ± SD	Mean ± SD	Mean ± SD	*P*
Receptive language age/month	69.9 ± 10.5[a]	62 ± 12.1[b]	53 ± 10.4[c]	<.01
Expressive language age/month	69.9 ± 10.5[a]	56.5 ± 9.1[b]	51.5 ± 7.6[c]	<.01
Receptive language score (TELD-3)	102 ± 3.1[a]	95.8 ± 7.5[b]	88.2 ± 8.1[c]	<.01
Expressive language score (TELD-3)	102.3 ± 3.4[a]	89.4 ± 8.3[b]	85.7 ± 9.4[c]	<.01
Verbal language performance	102.6 ± 3.7[a]	91.1 ± 8.8[b]	85.5 ± 8.7[c]	<.01

P < .05** was considered statistically significant. [b] and [c] are statistically significant compared to [a].

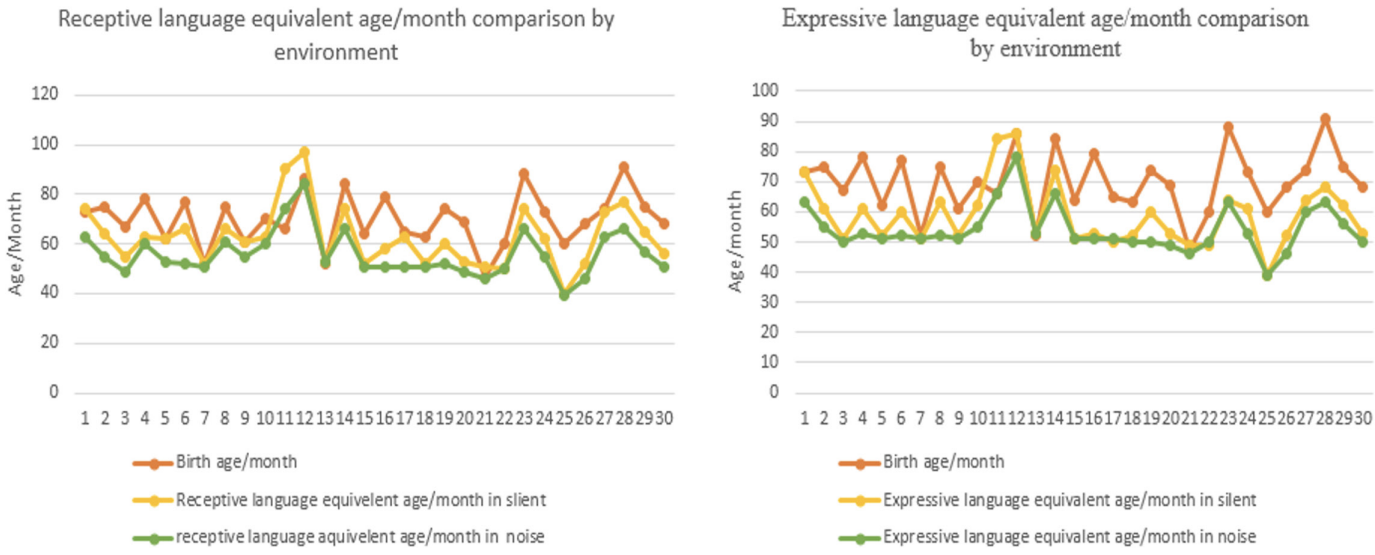

Figure 3. Patients' receptive and expressive language scores in quiet and noisy environments.

Table 5. Comparison of P1 /m/, /t/, /g/ Phonemes, Latency, and Amplitude Values

	Latency and Amplitude Values of P1 /m/, /t/, /g/ Phonemes in Quiet and Noisy Environments				Comparison of Latency and Amplitude Values of P1 /m/, /t/, /g/ Phonemes According to Months in Quiet and Noisy Environments			
	The Test Environment	Number of Patients	Mean ± SD	*P*	Months	Number of Patients	Latency and Amplitude Values of P1 /m/, /t/, /g/ Phonemes in Quiet and Noisy Environments	*P*
Latency values of P1(ms)				<.01**	47-59	3	.109	>.05
P1m latency	Quiet	25	105.5 ± 24		60-71	13	.002	<.01
	Noisy	25	123.6 ± 69		72-83	10	.005	<.01
					84-95	4	.068	>.05
P1t latency	Quiet	29	98.1 ± 17	<.01**	47-59	3	.109	>.05
					60-71	13	.014	<.05
	Noisy	29	132 ± 43		72-83	10	.005	<.01
					84-95	4	.465	>.05
P1g latency	Quiet	26	97.7 ± 22	<.01**	47-59	3	.180	>.05
					60-71	13	.033	<.05
					72-83	10	.024	<.05
	Noisy	26	122.6 ± 59		84-95	4	.715	>.05
Amplitude values of P1(μV)				<.01**	47-59	3	.285	>.05
P1m amplitude	Quiet	30	2.2 ± 2.2		60-71	13	.023	<.05
	Noisy	30	1.51 ± 1.7		72-83	10	.047	<.05
					84-95	4	.465	>.05
P1t amplitude	Quiet	30	5.4 ± 2.4	<.01	47-59	3	.109	>.05
					60-71	13	.002	<.01
	Noisy	30	1.91 ± 1.4		72-83	10	.005	<.01
					84-95	4	.068	>.05
P1g amplitude	Quiet	30	6.1 ± 2.6	<.01	47-59	3	.109	>.05
					60-71	13	.001	<.01
	Noisy	30	2.3 ± 2.0		72-83	10	.005	<.01
					84-95	4	.068	>.05

P < .05** was considered statistically significant. Amplitude was calculated in μV. Latency was calculated in ms.

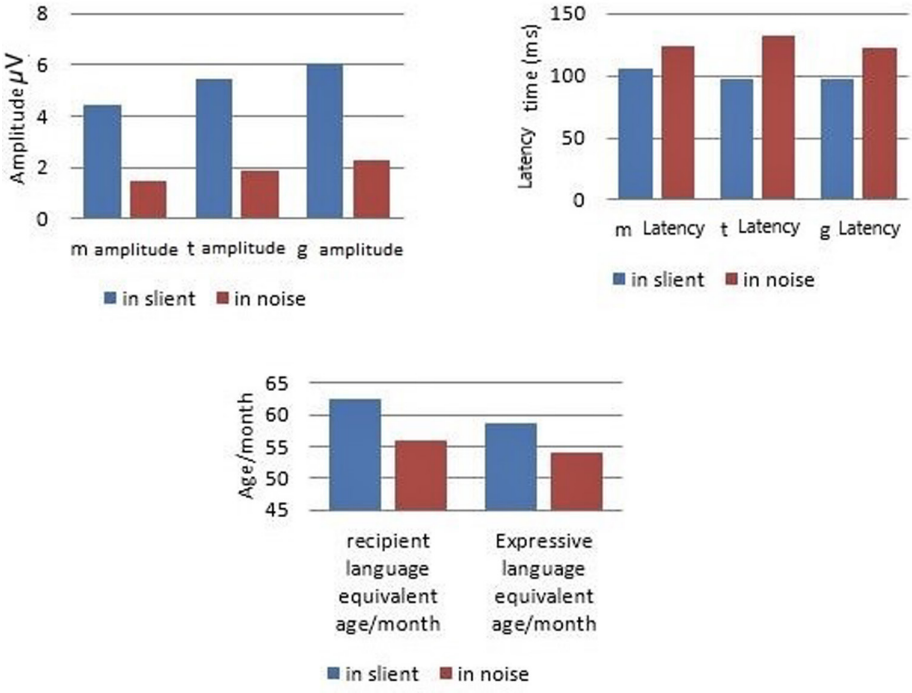

Figure 4. Amplitude and latency values of the patients' phonemes in quiet and noisy environments.

were on the desired levels. However, when the noise factor was added, a decrease in the amplitude values of all 3 phonemes was observed. The decrease caused by the introduction of the noise factor resulted in a statistically significant decrease in the amplitude values ($P < .01$). Simple linear regression analyses were performed to reveal the relationship between the duration of cochlear implant use and receptive and expressive language development of the patients who were included in the study. As a result, it was found that the duration of cochlear implant use had a positive effect on the receptive and expressive language development levels of the patients.

In this study, the scores of the patients in the language development tests (TELD-3) that were performed in the noisy environment were lower than their scores in those performed in the quiet environment. The TELD-3 test scores of the patients measured in the noisy environment were far behind their chronological ages ($P < .01$). On the other hand, no significant difference was found between language development levels in the measurements made in the quiet and noisy environments with respect to sex.

Discussion

As hearing loss progresses, the personalities, relationships, and general lifestyles of individuals are affected.[10,14] Among children, the maturation of the central auditory pathways before normal speech and language development and the subsequent phenomenon of neural plasticity are important.[10,15,16] Adequate auditory stimulation in childhood is necessary for the restoration and development of the ability of the central auditory system to recognize and distinguish sounds.[10,17]

Cochlear implants provide the necessary auditory stimuli for the development of verbal language, especially during the critical phase.[18,19] While the deep layers of the auditory cortex can mature without auditory stimuli, the superficial layer of the auditory cortex requires auditory stimuli in the early years of age to mature.[20] After the critical period, abnormalities are observed in the development of synaptic plasticity. This leads to abnormal connectivity between neuronal cells, functional fragmentation, and immaturity of auditory cortical areas. As a result, some auditory areas begin to take over non-auditory functions, leading to abnormalities in the restructuring of cognitive functions.[21]

One way to objectively measure the developmental status and limits of plasticity of the central auditory pathway is to examine changes in morphology and CAEP values with the P1-N1-P2 components.[22,23] The P1 wave of CAEPs is used to assess the maturation of the central auditory system in children. They are, therefore, useful in evaluating the effectiveness of auditory rehabilitation in children using individual hearing amplifiers and/or cochlear implants.[22] Cortical auditory-evoked potentials are used to assess the development and effectiveness of central auditory pathways, particularly in children with device-enhanced cochlear implants.

In this study, it was observed that the P1 latencies of the phonemes /m/t/g/ were longer in the patients in the noisy environment than in the quiet environment ($P < .01$). These results show compatibility with the literature.[24,25] Today, cochlear implantation is now performed under and/or around 1 year old. The main reason for this is the contribution of early implantation to language development[25,26]and the age at which surgical risks are best manageable.[27,28]

The literature has shown us that it has been observed that some children with cochlear implants lag behind their peers in language development.[28-31] The main reasons for this are related to the lack of adequate education after cochlear implantation and the socioeconomic levels of the families.[28,32,33]

Firszt et al. found that cochlear implant users often had difficulty understanding speech in noisy environments.[34] In this study, the scores of the patients in the language development tests that were administered in the noisy environment were lower than their scores in those administered in the quiet environment. In the comparison of the equivalent ages of the patients in the study based on their TELD-3 scores and their biological ages, it was found that the patients lagged behind their biological age in both the quiet and noisy environments. Additionally, the measurements made with the patients in the noisy environments revealed a lag far behind their biological ages. The language development of the patients who were included in the study was evaluated with TEDIL-3. In this context, the TEDIL-3 scores of the patients were very low compared to their peers in the noisy environment, whereas their TEDIL-3 scores were very close and/or comparable in the quiet environment (Figure 3). These results show compatibility with the literature.[34]

Studies on the language development of children with severe and profound hearing loss have revealed that children with hearing loss exhibit deficits in their receptive and expressive language development. In the study, all patients with cochlear implants had equivalent receptive and expressive language ages lagging behind their chronological age at the time of the study. The language development performance values of the patients in the noisy environment were found to be considerably lower than their language development performance levels measured in the quiet environment. After cochlear implantation, the proper educational program must be created and implemented for the child. The careful selection of instruction that supports the child's receptive and expressive language performance in these programs will improve the child's academic success, reading ability, reading comprehension, and writing skills in the future. It is believed that as these training programs are implemented, situations in which the cochlear implant device is not exposed to noise and has a sufficient level of noise suppression will have a positive impact on the individual's education and language development. It is also anticipated that cochlear implant technology will better suppress the noise factor in the future, show developments that will eliminate the noise factor that negatively affects an individual's perception, and have a positive impact on children's language development and hearing.

Data Availability Statement: The data that support the findings of this study are available on request from the corresponding author.

Ethics Committee Approval: Ethical committee approval was received from the Ethics Committee of University of Istanbul Cerrahpaşa University (Approval no: 355069, Date: October 04, 2016).

Informed Consent: Verbal/written informed consent was obtained from the patient(s) who agreed to participate in the study. The existing consent forms were submitted to the ethics committee and approved by the ethics committee.

Peer-review: Externally peer-reviewed.

Author Contributions: Concept – A.S., Z.P.; Design – A.S., Z.P.; Supervision – A.S., M.A.; Resources – M.A., Z.P.; Materials – A.S., Z.P.; Data Collection and/or Processing – A.S., Z.P.; Analysis and/or Interpretation – M.A., A.S.; Literature Search – M.A., Z.P.; Writing – A.S., M.A.; Critical Review – M.A., Z.P., A.S.

Declaration of Interests: The authors have no conflicts of interest to declare.

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