Temporal Processing and Speech Perception Performance in Postlingual Adult Users of Cochlear Implants

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Abstract

Background: Cochlear implant (CI) listeners had some hearing problems, including catching clues from speech context, persist, particularly in complex listening environments. Among these hearing problems, temporal resolution is considered to be one of the most affected aspects of hearing.

Purpose: The aim of the study is to assess and compare the temporal resolution ability of CI users and individuals with normal hearing using the Gaps-in-Noise (GIN) test. This study also aims to investigate whether there are any differences in speech recognition and temporal resolution performance between groups separated according to the implanted ear, gender, CI type, or sound processor strategies.

Research Design: Case-control study.

Study Samples: 18 adults (9 males, 9 females) with normal hearing, ranging in age between 18 and 55 years (mean: 30.64 ± 8.59 years) and 18 postlingual adults (10 males, 8 females) with bilateral CIs ranging in age between 19 and 59 years (mean: 36.64 ± 16.59 years) were included in the current study.

Data Collection and Analysis: Hearing thresholds, word recognition scores (WRS), and GIN test were conducted for each participant. Two parameters of GIN test were determined: the GIN threshold and total percentage score (TPS). Mann–Whitney U test was used to test the significance of the differences between the groups in terms of GIN threshold, WRS, and TPS.

Results: CI group showed significantly ($p < 0.001$) poorer performance in terms of WRS than normal hearing group. However there were no significant differences in WRS between groups which were divided according to the implanted ear, gender, CI type, and sound processor strategies. The mean GIN threshold was 3.33 ± 1.2 msec, whereas it was 9.56 ± 3.49 msec in CI users. Moreover the mean value of TPS was 90.77% in the normal group and 47.22% in the CI group. These differences between the two groups were also found statistically significant ($p < 0.001$).

Conclusions: Our results show that CI users do not discriminate GIN as well as normal-hearing individuals, although their hearing levels with CIs are very close to normal hearing limits at all frequencies.

Key Words: cochlear implants, speech perception, temporal resolution

Abbreviations: CI = cochlear implant; GIN = Gaps-in-Noise; TPS = total percentage score

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INTRODUCTION

Cochlear implants (CIs) are devices that were developed for restoring the hearing of individuals who have severe to profound hearing impairment. They convert acoustic sounds into electrical signals that directly stimulate the auditory nerve (Wilson and Dorman, 2008; Suh et al, 2015) Studies have shown that postlingually cochlear implanted adults exhibit good speech recognition performance in silence after CI surgery (Blamey et al, 2013; Zeng and Fay, 2013). Nevertheless, some hearing problems, including catching clues from speech context, persist, particularly in challenging listening conditions, such as noisy and reverberant conditions

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(Zeng et al, 2005). Among these hearing problems, temporal resolution is considered to be one of the most affected aspects of hearing (Kaiser et al, 1999). Restoring perceptual acuity in both the auditory spectral and temporal domains would be the ideal solution for this population.

Temporal resolution, which is one of the basic capabilities of the central auditory system, is used to express the ability to perceive or distinguish the smallest changes in an acoustic stimulus that continues over a specific period of time (Katz et al, 2009). It is also a fundamental component of speech processing (Rawool, 2007; Jack Katz et al, 2009). Temporal cues in auditory signals are the basis for speech recognition, especially for detecting voice onset time and offset time, and other transient parts of the stimuli. In this way, temporal resolution contributes to phonemic distinction, lexical and prosodic distinctions, and auditory closure (Tallal et al, 1993). Accurate speech recognition requires precise temporal processing because speech contains a multitude of contrastive frequency and timing cues. Several studies in the literature have suggested that temporal processing abilities are directly associated with speech perception (Cazals et al, 1991; Fu, 2002; Padilla et al, 2004). These studies support the idea that hearing is influenced by temporal cues in a variety of ways. However, some of these studies reported contradictory results. Shannon and Zwolan et al found no correlation between speech recognition and gap detection performance (Shannon, 1989; Zwolan et al, 1997), whereas in another study (Cazals et al, 1994), a moderate correlation was found. It is also well known that the capacity of speech understanding and temporal resolution vary widely among CI patients (Van Dijk et al, 1999). Although many CI users have excellent speech understanding performance, some need to use lip-reading cues to communicate. This variability can be related to many factors, such as audibility, duration of deafness, duration of CI use, and the etiology of deafness (Dowell et al, 1995; Blamey et al, 2013). But it is not easy to take into account all of these factors as the number of evaluated participants is small. When the role temporal characteristics play in speech perception is considered, the importance of evaluating the temporal resolution performance of CI users is evident. However, in the literature, only a few studies have evaluated the temporal resolution abilities of CI users. Moreover, there is no consensus on which factors enable CI recipients to acquire the ability to detect gaps and to understand speech. Therefore, this study aimed at the following:

- To assess and compare the temporal resolution ability of CI users and individuals with normal hearing using the Gaps-in-Noise (GIN) test
- To investigate the relationship between temporal resolution and speech recognition scores in both normal hearing and CI user groups
- To investigate whether there are any differences in speech recognition and temporal resolution performance between groups separated according to the implanted ear, gender, CI type, or sound processor strategies
- To investigate whether the age at testing and the duration of CI use have an effect on temporal resolution and speech perception performance in the CI group

METHOD

Two groups were included in the study. These groups were matched for age, gender, and number of participants. The first group consisted of 18 adults (9 males, 9 females) with normal hearing, ranging in age between 18 and 55 years (mean: 30.64 ± 8.59 years). Normal hearing was defined as having pure-tone thresholds within 25-dB HL at octave frequencies between 250 Hz and 8 kHz and normal results on immittance evaluation.

The second group consisted of 18 adults (10 males, 8 females) with CIs ranging in age between 19 and 59 years (mean: 36.64 ± 16.59 years). All of them had bilateral postlingually severe to profound hearing loss and at least one-year experience with their implants.

The mean of warble-tone thresholds with their implants at the free field was around 30-dB HL at octave frequencies from 250 to 8000 Hz (Figure 2). Detailed demographic information is shown in Table 1.

None of the participants had any neurological, cognitive, or learning disorders.

The research was initiated only after receiving approval from the Clinical Studies Ethics Committee at Marmara University Health Sciences Institute, protocol No: 09.2018.795. An informed consent form was obtained from all participants.

PROCEDURES

After assessing the hearing thresholds, speech tests and a GIN test were conducted for each participant. All tests were performed in a soundproof room with an ambient noise level below 30-dB (A) SPL.

In the normal hearing group, pure-tone air (between 250 and 8000 Hz) and bone conduction (between 250 and 4000 Hz) hearing thresholds were assessed using the Interacoustics AC40 audiometer (Interacoustics A/S, Assens, Denmark) and TDH 39 earphones (Telephonics, Farmingdale, NY). In the CI user study group, free-field air conduction hearing thresholds were obtained using warble tone (between 250 and 8000 Hz) through a speaker that was positioned 1 meter away from the participant, positioned at 0° azimuths.

Phonemically Balanced Turkish monosyllabic word recognition lists were used in the speech recognition test (Durankaya et al, 2014). These lists consist of 6 different sets of 25 words. The words in the lists were recorded by a female speaker in a professional sound recording studio. While recording, the microphone was placed 15 cm away

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from the speaker's mouth at an angle of 45°. Postrecording normalization was performed for each part of the test, and the highest dB SPL value obtained from the sound samples was calculated. The peak point in each spectrum was designated as 65-dB SPL, and other frequency intensities were derived in relation to this peak point. The test was conducted in a without-noise condition in which the speech signal was presented at 65-dB SPL. Both the speech tests and the GIN test stimuli were calibrated with reference to a 1000-Hz probe tone in the free field.

After performing the procedures mentioned previously, all participants were submitted to an auditory temporal resolution assessment with the GIN test. The GIN test consists of 4 different test lists that contain a series of 29 to 36 segments. Each segment consists of a six-second burst of broadband noise, which contains zero to three silent gaps ranging from 2 up to 20 msec (Musiek et al, 2005). The calibrated stimuli of the GIN test, which were transferred from the CD player to the calibrated audiometer, were played through a loudspeaker at the level of 65-dB SPL in the free field. During the test, participants were asked to press the response button when they identified a gap. Before the actual GIN test, participants took a practice test to ensure that each of them was familiar with the test. Initially, 23 postlingually cochlear implanted users were enrolled in the study, but five were excluded because they failed to complete the GIN test, despite having taken the practice test. All normal hearing participants completed the GIN test.

At the end of the test, two parameters were determined: the GIN threshold and total percentage score (TPS). The GIN threshold is defined as the shortest gap for which the following two criteria hold: (a) correctly identified at least four out of six times and (b) performance for any of the longer gaps is not worse.

The TPS was calculated according to the following formula:

TPS = ([Total correct responses/60] $\times$ 100) (Musiek et al, 2005).

STATISTICAL METHODS

IBM SPSS Statistics for Windows, Version 20.0 (International Business Machines-Statistical Package for Social Sciences, Chicago, IL) was used for statistical analysis. The Kolmogorov–Smirnov Test was used to examine whether the groups showed normal distribution or not. As the data were not normally distributed, nonparametric tests were used. Mann–Whitney U test was used to test the significance of the differences between the groups in terms of GIN threshold, word recognition score (WRS), and TPS, and the differences between the groups separated according to the implanted ear, gender, CI type, and sound processor strategies were analyzed with the independent samples Kruskal–Wallis test. To examine the relationship between the variables (GIN thresholds, TPS, WRS, the age at testing, and the duration of CI use), the Spearman's correlation coefficients test was used. p values <0.05 were accepted as statistically significant for all statistical analyses.

Table 1. Demographic Information for the CI Participants

Participant	Gender	Age of Implantation	Age at Test (years)	Ear	Duration of CI Use (years)	Etiology	Device Type	Strategy
1	F	16	22	R	6	LVA	Nucleus 5	ACE
2	M	54	60	L	4	Unknown	MED-EL opus 2	FS4-P
3	F	49	59	L	10	Unknown	MED-EL opus 2	FSP
4	F	25	29	R	4	Sudden	Nucleus 5	ACE
5	F	51	62	R	11	Unknown	MED-EL opus 2	FSP
6	M	16	26	L	10	Meningitis	MED-EL opus 2	FSP
7	F	15	20	L	5	Unknown	Nucleus 6	ACE
8	M	7	19	R	12	Unknown	Nucleus 5	ACE
9	M	39	40	L	1	Unknown	Nucleus kanso	ACE
10	M	34	35	R	1	Unknown	Nucleus 6	ACE
11	M	49	59	R	10	Otosclerosis	MED-EL opus 2	FSP
12	M	32	37	L	5	Unknown	Nucleus 6	ACE
13	F	16	21	L	5	Unknown	Nucleus 6	ACE
14	M	19	24	R	5	Unknown	Nucleus 5	ACE
15	F	12	29	R	17	Unknown	Nucleus 5	ACE
16	M	42	51	L	9	Sudden	MED-EL opus 2	FS4-P
17	M	17	20	R	3	Unknown	MED-EL opus 2	FS4-P
18	M	15	21	R	6	Meningitis	MED-EL opus 2	FS4-P

Notes: ACE = advanced combination encoder; F = female; FSP = fine structure processing; FS4-P = parallel signal processing; L = left; LVA = large vestibular aqueduct; M = male; R = right.

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Table 2. Differences between the Groups in Terms of GIN Thresholds, TPS, and WRS

		Two-Tailed p Value		
Groups	Number of Participants	GIN Threshold	TPS	WRS
Implanted ear				
Right	11	0.285	0.479	0.596
Left	7			
Gender				
Female	7	0.479	0.659	0.596
Male	11			
CI type				
MED-EL	8	0.146	0.1734	0.897
Nucleus	10			
Strategies				
ACE	10	0.084	0.065	0.661
FSP	4			
FS4-p	4			

RESULTS

Audiometric Assessments

The mean pure-tone average was 12.43 ± 5.66 dB HL at 500–4000 Hz in the normal group (Figure 1) and was 30 ± 5.69 dB HL at 500–4000 Hz in the CI group (Figure 2).

Speech Recognition Tests

The speech recognition thresholds were between 10- and 20-dB HL, and the average was 12.5 dB in the normal group, whereas in the CI user group, thresholds were between 15- and 30-dB HL, and the average was 27.5-dB HL. In the normal hearing group, word recognition scores ranged from 92% to 100%. In the CI user group, they were between 24% and 88%, and highly variable across the users. The mean of the word recognition score was 98.44% in the normal hearing group, whereas it was 60.22% in the CI user group. The difference in word recognition scores between the normal hearing and CI groups was significant ($p \leq 0.001$). But there were no significant differences in WRS between groups which were divided according to the implanted ear, gender, CI type, and sound processor strategies (Table 2). Also, there was no relationship between WRS and neither the age at testing ($r = 0.108$, $p = 0.335$) nor the duration of CI use ($r = 0.247$, $p = 0.162$).

GIN Test

All participants in both groups were able to complete the GIN test. Whereas all GIN thresholds in the normal hearing group were within normal limits (≤5 msec), the results were variable in the CI group. The results of each partcipant are shown in Figure 3. In the normal hearing group, the mean GIN threshold was 3.33 ± 1.2 msec, whereas it was 9.56 ± 3.49 msec in CI users (Figure 3). This difference between the two groups was statistically significant ($p < 0.001$). The mean value of TPS was 90.77% in the normal group and 47.22% in the CI group. This difference between the two groups was also statistically significant ($p < 0.001$). The mean of GIN test scores and differences between the normal hearing and CI user groups are displayed in Figure 3 and 4, respectively.

There was a strong negative correlation between the GIN threshold and TPS in both groups ($r = -0.901$, $p < 0.001$ in the normal group, $r = -0.933$, $p < 0.001$ in the CI user group).

There were no significant differences in GIN scores (GIN thresholds and TPS) between groups which were divided according to the implanted ear, gender, CI type, and sound processor strategies (Table 2). Also, there was no relationship between GIN scores and neither the age at testing (GIN thresholds [$r = 0.109$, $p = 0.333$]; TPS [$r = -0.254$, $p = 0.155$]) nor the duration of CI use (GIN thresholds [$r = -0.203$, $p = 0.209$]; TPS [$r = 0.243$, $p = 0.165$]).

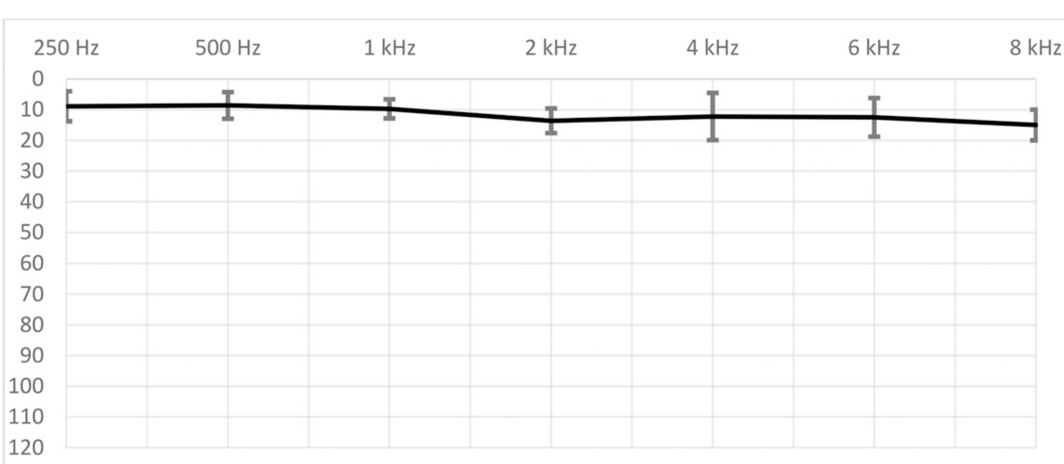

Figure 1. Mean of pure-tone thresholds at 250–8000 Hz in the normal hearing group.

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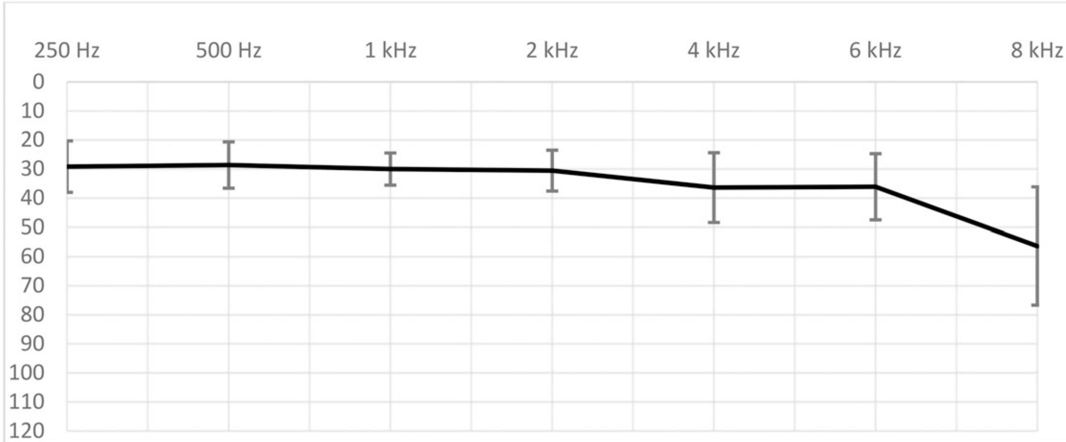

Figure 2. Mean of free-field warble-tone thresholds with CI at 250–8000 Hz in the CI user group.

Relationship between GIN and Word Recognition Scores

There was no significant correlation between GIN results and word recognition scores obtained in the normal hearing group (GIN thresholds [$r = 0.014$; $p = 0.957$]; TPS [$r = -0.084$; $p = 0.741$]).

There was no significant correlation between GIN results and word recognition scores obtained in the CI user group either (GIN thresholds [$r = -0.186$; $p = 0.461$]; TPS [$r = 0.194$; $p = 0.441$]).

DISCUSSION

Our results show that CI users do not discriminate GIN as well as normal-hearing individuals, although their hearing levels with CIs are very close to normal hearing limits at all frequencies. This phenomenon may be related to the effect of peripheral auditory processes. The effect of peripheral processes on the temporal resolution is not negligible. Electrical stimulation generated by CI is significantly different from the natural stimulation of the cochlea (Kirby and Middlebrooks, 2009; Duarte et al, 2016). It is obvious that CI cannot completely fulfill the functions of the cochlea. A normal cochlea has a large number of independent channels that affect the temporal and spectral processing, whereas the number of channels of CI is limited (Zeng and Fay, 2013). Hence, the information delivered by CI to the auditory system is degraded. In this study, we found that the temporal resolution abilities of CI users were significantly low compared with normal participants. These findings corroborate studies by Zeng et al (1999), Duarte et al (2016), and Sales de Meneses et al (2014), in which they found that CI users have considerably low gap detection performance compared with normal hearing participants. However, it is found that these declines in temporal resolution do not affect

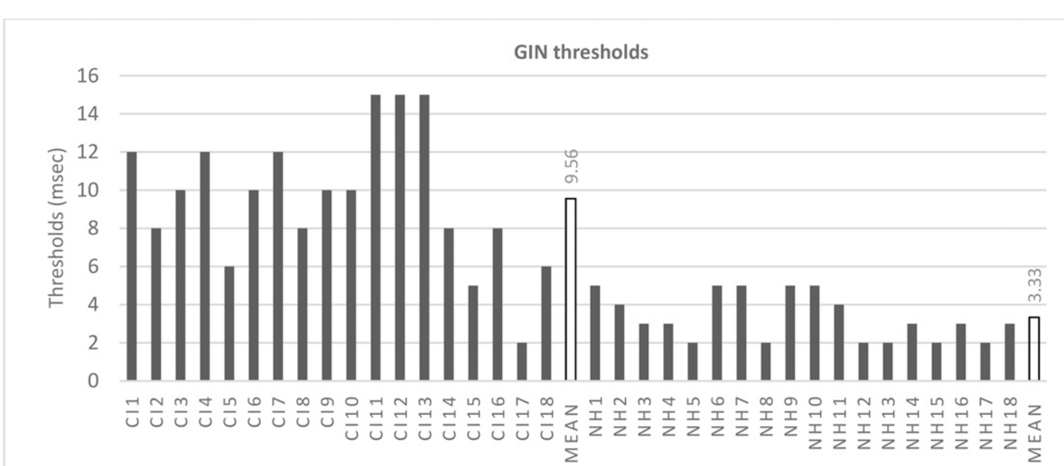

Figure 3. GIN threshold for each participant.

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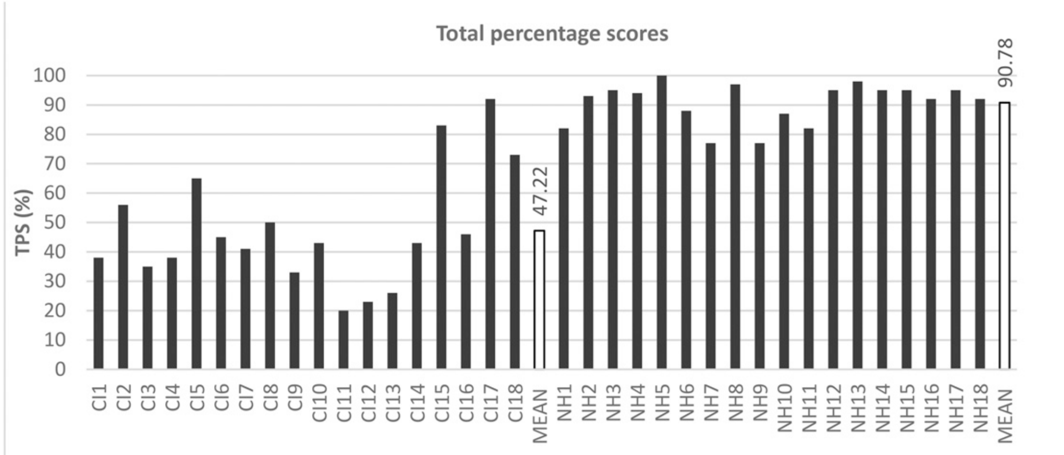

Figure 4. TPS for each participant.

speech perception in quiet. Similar to our results, in some studies, only moderate correlation (Cazals et al, 1994; Busby and Clark, 1999) or no correlation (Shannon et al, 1998) between speech and gap detection performance was found. In contrast to these, in many other studies, it was found that there was a close correlation between temporal processing and speech recognition performance (Merzenich et al, 1996; Zeng et al, 1999; Phillips et al, 2000). Temporal resolution requires the auditory pathways to be intact. However, speech recognition requires cognitive processes, such as attention, memory, and intelligence, as well as intact auditory pathways. The existence of various factors, such as peripheral, central, and cognitive processes, makes it difficult to evaluate the effect of temporal resolution on speech comprehension problems alone. Likewise, it can be suggested that temporal resolution may be related to speech recognition performance in the presence of noise. In future studies, speech recognition skills should also be assessed in noisy conditions.

In our study, it was also investigated whether the age at testing and duration of CI use have an effect on temporal resolution and speech perception performance, and no significant correlation was found between these variables. However, there are some limitations that are important to interpret the results of our study. It is well known that there are many other factors which correlate with the performance of CI users in different auditory skills. Onset of deafness, residual hearing, duration of hearing loss, etiology, and preoperative auditory performance are some of these factors (Kirk, 2000; Clark, 2003). Moon et al found that the age of implantation, the age of onset of deafness, and the duration of deafness adversely affected the CI outcome, and they suggested that onset of deafness was the most important factor (Moon et al, 2014). In our study, except five participants, the etiology of hearing loss was unknown and almost all participants had progressive sensorineural hearing loss. So, it was unclear since when they had severe hearing loss. Therefore, the auditory deprivation effect is impossible to estimate, even if the age at the onset of hearing loss is known. Although, in a previous study, it was suggested that the auditory deprivation time does not play a predictive role in CI performance in participants with postlingual hearing loss (Medina et al, 2017), it is known that auditory deprivation is an essential factor during the critical process of maturation of the auditory system (Lazard et al, 2012).

In this study, the factors that have larger effects on the ability to detect gaps and understand speech in the CI users were also investigated. There were no significant differences in terms of both gap detection and word recognition scores between the groups which were divided according to the implanted ear, gender, CI type, and sound processor strategies. It can be argued that this division according to different factors has led to even smaller groups, making the results harder to generalize. However, in a larger study conducted by Lazard et al (2012), it was concluded that gender, education level, and implanted ear does not affect CI performance. In the same study, it was observed that the pure-tone average threshold of the better ear, CI brand, the percentage of active electrodes, the use of hearing aids during the period of profound hearing loss, and the duration of moderate hearing loss were the most significant factors (Lazard et al, 2012).

In conclusion, in this study, it was observed that both temporal resolution and speech perception performance are significantly poorer in CI users than in the normal hearing group. However, these performances were not correlated with each other. It can be suggested that temporal resolution has more influence on auditory recognition by helping to capture acoustic cues in complex

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listening environments, such as ones with noise. Therefore, in future studies, the contribution or effect of temporal resolution on speech recognition in noisy environments can be investigated. In addition, the effects of implant programming strategies on temporal resolution can also be investigated using large-scale studies. There are many factors in the literature that have been suggested to be effective on CI outcomes. However, it is seen that the results vary between studies (Clark, 2003; Lazard et al, 2012; Schaefer et al, 2017). In this study, there were no significant differences in temporal resolution and speech recognition performance between the groups based on the impanted ear, gender, implant type, and strategy. However, because of the low number of participants with CI in the study, it is thought that the results will not be sufficient for generalization. In future studies, it is recommended to carry out more comprehensive studies that control variables and involve more participants.

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