Aud Vest Res (2017);26(3):138-144.

RESEARCH ARTICLE

Aural/oral performance in children with bimodal stimulation or unilateral cochlear implant

Fatemeh Garousi[1], Homa Zarrinkoob[1*], Vahid Moradi[2], Hessamaldin Emamdjomeh[3], Alireza Akbarzadeh Baghban[4]

[1]- Department of Audiology, School of Rehabilitation, Shahid Beheshti University of Medical Sciences, Tehran, Iran

[2]- Department of Audiology, School of Rehabilitation, Tehran University of Medical Sciences, Tehran, Iran

[3]- ENT and Head & Neck Research Center, Iran University of Medical Sciences, Tehran, Iran

[4]- Proteomics Research Center, Shahid Beheshti University of Medical Sciences, Tehran, Iran

Received: 17 Jan 2017, Revised: 26 Jan 2017, Accepted: 4 Feb 2017, Published: 15 Jul 2017

Abstract

Background and Aim: Sound processors in cochlear implant (CI) cannot encode low frequency information and discard much of the temporal fine structure required to perceive fundamental frequency. Hearing aids can transmit low frequency information, which is important for pitch perception and provides many advantages for the users. This study aimed to compare aural/oral performance of bimodal cochlear implants with unilateral ones in children using parents' evaluation of aural/oral performance of children (PEACH) questionnaire.

Methods: Twenty children with unilateral cochlear implant and 20 ones with bimodal cochlear implants were selected for this study. Of them, 23 had cochlear devices, 10 possessed Med-El ones, and 7 wore advanced bionics ones. Bimodal group had at least 7 months of hearing experience with digital hearing aid in non-implanted ear. In order to compare the aural/oral performance in these groups, we used the PEACH questionnaire.

Results: In unilateral and bimodal groups, age of implantation and age of testing and hearing experience before CI use were not significantly different. However, there was a significant difference in quiet score, noise score, and total score between unilateral and bimodal groups ($p<0.05$).

Conclusion: In bimodal group, aural/oral performance was significantly improved in quiet and noise situations in comparison with unilateral group. This improvement is due to the advantage of binaural processing and low frequency information provided by the hearing aid.

Keywords: Bimodal stimulation; unilateral cochlear implant; aural/oral performance

* **Corresponding author:** Department of Audiology, School of Rehabilitation, Shahid Beheshti University of Medical Sciences, Damavand Ave., Tehran, 1616913111, Iran. Tel: 009821-77561721
E-mail: homa_zarrinkoob@yahoo.com

Introduction

Improvements in cochlear implant (CI) technology and relaxation of implant candidacy have extended the cochlear implantation inclusion criteria of patients with residual function of low frequency hearing. This residual hearing can be accessed through acoustic stimulation provided by a hearing aid in non-implanted ear [1].

Unfortunately, cochlear implant processors do not adequately convey low frequency information since a low-order harmonic and fundamental frequency (F0) does not participate in speech perception [2]. This deficiency adversely affects pitch perception [3]. However, hearing aids transmit low frequency information and provide many advantages for users. Lower frequencies provide more information about the place and manner of articulation [4] as well as a pitch cue that allows bimodal users to segregate concurrent sound sources in competing listening sounds [5]. Also, Li and Loizou have shown that more low frequency cues enhance the listener's ability to glimpse the target because electrical-acoustical stimulation increases the signal-to-noise ratio (SNR) [6].

Bimodal hearing also provides binaural cues to the upper levels of the auditory pathways and enables the utilization of binaural processing required for segregation of speech in complex listening conditions. Binaural processing mechanisms such as binaural redundancy, binaural squelch, head-shadow effect, and binaural summation distinctly improve speech perception when signal and noise sources are spatially separated or concurrent in space [3,7,8]. Speech recognition tests have shown that electrical-acoustical stimulation (cochlear implant in one ear and hearing aid in the other) may be advantageous when listening to speech in quiet or noisy conditions [1] and also listening to music and other non-speech sounds [9]. Moreover, it improves sound localization [10] and perceived sound quality that finally leads to more user satisfaction [9].

We used parents' evaluation of aural/oral performance of children questionnaire (PEACH) to assess the effectiveness of amplification in children [11]. This questionnaire was developed to evaluate amplification for children across a wide range of ages and hearing loss severities. It consists of two items that provide information about utilization of hearing aids/cochlear implants and loudness comfort. Eleven items assess aural/oral performance in quiet and noisy environments as well as the use of telephone and response to environmental sounds [11]. By means of PEACH questionnaire, the benefits of hearing aid use in non-implanted ear in children with unilateral cochlear implant can be quantified in quiet and noise subscale scores. The PEACH scale was translated and adapted into Persian language [12].

The purpose of the present study was to compare aural/oral performance between children with bimodal and unilateral cochlear implants using the PEACH questionnaire.

Methods

Twenty children with unilateral cochlear implants (10 boys and 10 girls) and twenty children with bimodal stimulation (10 boys and 10 girls) were selected through non-probability convenience sampling method. The biographical data are shown in Table 1 for unilateral cochlear implant group and in Table 2 for bimodal stimulation group. All parents of children gave their written informed consent prior to inclusion in the study.

In unilateral CI group, the mean (SD) age of implantation was 27.15 (4.17) months (range: 19-34 months), and their age at the time of testing ranged from 45 to 60 months with mean (SD) of 51.45 (4.46) months. At the time of testing, patients had the mean (SD) period of 24.30 (3.97) months of hearing experience with the CI. In bimodal group, the mean (SD) age of implantation was 26.40 (4.31) months (range: 20-34 months) and their age at the time of testing ranged from 48 to 60 months with mean (SD) of 52.75 (3.97) months. At the time of testing, patients had the mean duration of 26.25 months of hearing experience with the CI and had the mean period of 15.90 months (range: 7-21 months) of hearing experience with the super power digital hearing aid.

The administration and scoring methods for PEACH questionnaire closely followed the guidelines for the PEACH scale as described by Ching and Hill [11]. The parents were asked to observe their children's auditory and oral behaviors and record their behaviors in a booklet in a 1-week period using a 5-point scale ranging from 0 to 4 points. Scoring was carried out by an audiologist based on the number and frequency of auditory and oral behaviors. The response points were as follows: 0=never, 1=seldom bout 25% of the time), 2=sometimes (around 50% of the time), 3=often (about 75% of the time), and 4=always (100% of the time).

Table 1. Biographical data of unilateral group

Patient	Sex	Etiology	Ear	Type of CI device	Sound processor	Age (months) At cochlear implantation	Age (months) At testing	Duration of haring aid use before CI
1	M	Family history	R	Cochlear	CP800	31	52	15
2	F	Family history	R	Med-El	OPUS2	26	45	13
3	F	Ototoxity	R	Cochlear	CP900	29	58	18
4	M	Unknown	R	Med-El	OPUS2	25	51	10
5	M	Meningitis	R	Cochlear	CP800	28	48	9
6	F	Ototoxity	R	Cochlear	CP900	26	48	11
7	M	Family history	R	Cochlear	CP900	33	56	17
8	M	Family history	R	Advanced Bionic	Harmony	32	56	18
9	F	Family history	R	Cochlear	CP800	24	51	11
10	M	Family history	L	Cochlear	CP900	22	45	12
11	M	Unknown	R	Med-El	OPUS2	27	47	14
12	F	Unknown	R	Cochlear	CP800	23	48	10
13	F	Family history	L	Cochlear	CP900	19	49	11
14	M	Family history	R	Med-El	OPUS2	23	53	12
15	M	Family history	R	Cochlear	CP900	29	50	19
16	F	Family history	R	Cochlear	CP900	32	54	12
17	M	Meningitis	R	Med-El	OPUS2	34	54	17
18	F	Family history	R	Advanced Bionic	Harmony	30	60	16
19	F	Family history	R	Cochlear	CP900	28	58	16
20	F	Unknown	R	Advanced Bionic	Harmony	22	51	14

CI; cochlear implant, M; male, F; female, R; right, L; left

The scores of quiet and noisy conditions were calculated as follows: the sum of points of questions 3,4,7,8,11, and 12 was divided by 24 for obtaining the percentage of quiet score. The sum of points of questions 5,6,9,10, and 13 was divided by 20 for obtaining the percentage of noise score. The sum of points of questions 3 to 13 was divided by 44 to calculate the total score [11,13].

Normality of quiet, noise, and total scores were confirmed using Shapiro-Wilk test before analysis. We compared all the scores using independent t-tests. The significant level was set at $p<0.05$.

Results

No significant differences were found in mean and standard deviation for age of implantation, age at the time of testing and duration of hearing aid use before cochlear implantation between two groups ($p>0.05$). The means (standard deviation) and p values are presented in Table 3.

Table 2. Biographical data of bimodal group

Patient	Sex	Etiology	Ear	Type of CI device	Sound processor	Type of hearing aid	Age (months)		Duration of haring aid use before CI	Duration of hearing aid use after CI
							At cochlear implantation	At testing		
1	M	Family history	R	Cochlear	CP900	Phonak	22	53	11	21
2	F	Family history	R	Cochlear	CP900	Siemens	30	49	17	16
3	M	Family history	R	Advanced Bionic	Harmony	Phonak	28	60	15	15
4	F	Unknown	R	Med-El	OPUS2	Unitron	24	54	17	8
5	M	Unknown	L	Cochlear	CP800	Oticon	20	49	9	15
6	F	Unknown	R	Cochlear	CP900	Phonak	32	51	21	12
7	M	Unknown	R	Advanced Bionic	Harmony	Phonak	28	56	15	21
8	M	Unknown	R	Cochlear	CP900	Phonak	24	49	12	18
9	F	Family history	R	Med-El	OPUS2	Oticon	21	53	11	16
10	M	Family history	R	Cochlear	CP900	Widex	31	57	14	7
11	M	Unknown	R	Cochlear	CP900	Unitron	21	52	10	15
12	F	Family history	R	Med-El	OPUS2	Oticon	34	56	17	13
13	M	Meningitis	R	Cochlear	CP900	Phonak	23	48	9	9
14	F	Family history	R	Advanced Bionic	Harmony	Phonak	25	54	14	20
15	F	family history	R	Cochlear	CP900	Widex	32	55	21	18
16	M	Family history	R	Med-El	OPUS2	Phonak	22	50	8	21
17	F	Family history	R	Cochlear	CP900	Starkey	26	51	10	18
18	F	Unknown	R	Med-El	OPUS2	Siemens	32	54	14	17
19	M	Unknown	R	Cochlear	CP900	Unitron	26	52	18	20
20	F	Family history	R	Advanced Bionic	Harmony	Phonak	23	51	9	18

CI; cochlear implant, M; male, F; female, R; right, L; left

The mean (standard deviation) values for quiet, noise, and total scores are presented in Table 4. There were significant differences in quiet, noise, and total scores between unilateral cochlear implant group and bimodal stimulation group ($p<0.05$).

Discussion

In this study, we found that bimodal stimulation had significant effects on aural/oral performance in quiet and noisy conditions compared with unilateral cochlear implant.

Using hearing aid in the non-implanted ear

Table 3. Mean (standard deviation) for age at implantation, age at testing and duration of hearing aid use before cochlear implantation in bimodal and unilateral cochlear implanted group

	Unilateral cochlear implant group	Bimodal group	p
Age at implantation (month)	27.15 (4.17)	26.40 (4.31)	0.292
Age at testing (month)	51.45 (4.46)	52.75 (3.97)	0.636
Duration of hearing aid use before CI (month)	13.75 (3.07)	13.60 (4.00)	0.895

CI; cochlear implant

results in binaural advantages that are not possible for unilateral cochlear implant. It has been shown that bimodal CI users are more satisfied than unilateral CI users due to improved speech perception, especially in noisy condition, improved localization ability, and better sound quality [9,10,14,15].

The underlying advantages for electrical-acoustical stimulation (EAS) in speech perception include two mechanisms. First, acoustic representation of fundamental frequency (F0) improves speech recognition through increased access to consonant cues and prosodic cues [16]. Sheffield and Zeng reported that the F0 cue provides voicing and manner of information, which improves consonant recognition. Also, the lower frequency cues provide additional manner, place, and formant cues that improve both consonant and vowel recognition [1]. Low frequency information, such as F0, improves pitch cues, also F0 is a strong cue for sound source segregation [17]. Several studies have shown that F0 information, which is provided by hearing aid, can help the patient segregate sound sources in bimodal listening situations [18,19]. All these advantages lead to an improvement of speech reception, especially in noisy conditions [20-22].

The second underlying mechanism for bimodal stimulation advantages in speech perception includes binaural summation, binaural redundancy, head-shadow, and binaural squelch [3,8]. Bimodal stimulation can provide binaural input to central auditory system and binaural processing separates speech and noise sources [23]. Binaural redundancy refers to the improvement in speech reception when the speech and noise are audible in both ears rather than in only one ear along with the improvement of the SNR. When signal and noise originate from spatially separated sources, SNR improves by analyzing inter aural time and level differences of the signal arriving at each ear, and this mechanism is referred to as head-shadow effect. Now when the SNR is equal in both ears, interaural time difference (ITD) and interaural level difference (ILD) can improve the effectiveness of SNR by reducing the impact of noise on speech

Table 4. Comparison of parents' evaluation of aural/oral performance of children mean (standard deviation) scores between unilateral and bimodal groups in quiet, noisy and total conditions

Score (%)	Unilateral cochlear implant group	Bimodal group	p
Quiet score	66.45 (10.06)	75.41 (9.92)	0.007
Noise score	54.50 (10.11)	70.25 (10.07)	<0.001
Total score	61.01 (9.59)	71.06 (9.87)	<0.001

intelligibility. This phenomenon is referred to as binaural squelch [24,25]. All these mechanisms lead to better speech recognition in quiet and noisy environments in electrical-acoustical stimulation [3].

Conclusion

For the bimodal group, aural/oral performance significantly improved in quiet and noisy situations compared to unilateral cochlear implant group. The advantage of bimodal hearing was found in listening and communication in quiet and noisy conditions and responses to environmental sounds.

Acknowledgments

This research is adopted from F. Garousi's MSc. dissertation and supported by grant No. 267 from Shahid Beheshti University of Medical Sciences. We greatly appreciate the families of study children for participation in this study and Fatemeh Arbabi for assistance in data collection.

Conflict of interest

The authors declared no conflicts of interest.

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