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Cortical auditory plasticity in children with Cochlear implants

Mozafar Sarafraz[1], Meysam Kiani[1], Arash Bayat[2], Soheila Nikakhlagh[1], Majid Karimi[3], Mina Riahi[4], Nader Saki[5]

ABSTRACT

Objectives: The purpose of the current study was to investigate plasticity of auditory system following cochlear implants (CI) in prelingually severe to profound hearing-impaired children using cortical auditory evoked potentials (CAEPs) and correlate it with auditory perception performance.

Methods: A total of 28 (15 boys, 13 girls) children with profound hearing loss, who underwent CI at Ahvaz Jundishapur University of Medical Sciences, Iran, were included in this study. Their mean age at the time of implantation was 21.3 months. All children were evaluated before implantation and 3 months after implantation using the CAEPs and categorical auditory performance (CAP). For CAEP measurement, the stimuli on the HEARLab system (/m/, /g/, and /t/) were extracted from running speech and presented at 65 dB SPL.

Results: The mean CAP and P1 amplitude values were increased from pre-CI condition to 3-month post-CI condition (Paired t-test, $p<0.001$). We found a positive correlation between P1 amplitude and CAP score changes from pre- to post-implantation stages (Pearson's $r=0.62$, $p=0.018$). There was no significant difference in CAP and P1 amplitude values between boys and girls ($p>0.05$).

Conclusion: The present study indicated that early cochlear implantation, will improve cortical auditory plasticity and auditory performance ability in pre-lingual hearing-impaired children.

Keywords: Cochlear implantation, categorical auditory performance, plasticity, children

INTRODUCTION

Normal development of the auditory cortex is largely dependent on sufficient auditory stimulation. Because of the increased potential of the cortex to be altered during early childhood period, either auditory stimulation or auditory deprivation can seriously influence the maturation of auditory cortical structures and associated behavioral abilities (1,2).

Cochlear implants (CIs) are the most effective neural prosthesis for delivering auditory inputs to individuals with severe to profound hearing loss by bypassing the damaged cochlea and directly stimulating the auditory nerves (3-5). It seems that within 3-6 month post-implantation, auditory cortex undergoes significant reorganization and some alternations in stimulus processing and discrimination can be seen within days after the initial processor fitting (6-9).

The neurocognitive functions related to the perception of acoustic stimuli can be studied by recording cortical auditory evoked potentials (CAEPs). CAEPs are beneficial methods for the objective assessment of central auditory processing, and neural encoding of speech stimuli. These

Potentials are non-invasive and do not depend on subject attention on a specific task, and can be used to evaluate individuals who cannot adequately cooperate (10-12).

The first CAEP component observed, P1, reflects the processing of acoustic stimuli at the thalamo-cortical level and in primary auditory cortex. Recent evidences have shown that the P1 can be utilized for objectively predicting CI outcomes as well as improving candidacy and implant programming (13-16). The presence of P1 following activation of

[1] *Hearing Research Center, Imam Khomeini Hospital, Ahvaz Jundishapur University of Medical Sciences, Ahvaz, Iran*
[2] *Musculoskletal Rehabilitation Research Center, School of Rehabilitation Sciences, Ahvaz Jundishapur University of Medical Sciences, Ahvaz, Iran*
[3] *Department of Audiology, School of Rehabilitation Sciences, Iran University of Medical Sciences, Tehran, Iran*
[4] *Critical Care Department,University of Manitoba,Winnipeg,Canada*
[5] *Hearing Research Center, Ahvaz Jundishapur University of Medical Sciences, Ahvaz, Iran*

Correspondence: *Nader Saki*
Hearing Research Center, Ahvaz Jundishapur University of Medical Sciences, Ahvaz, Iran

E-mail: ahvaz.ent@gmail.com

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Table 1: *The capacity of auditory performance (CAP)*

Category	Criteria
0	No awareness of environmental sounds
1	Awareness of environmental sounds
2	Response to speech sounds
3	Identification of environmental sounds
4	Discrimination of some speech sounds without lip-reading
5	Understanding of common phrases without lip-reading
6	Understanding of conversation without lip-reading
7	Use of telephone with known listener

the CI devices supports the assumption that the deep layers of auditory cortex may develop to some extent even in the absence of auditory stimulation.

The purpose of the current study was to investigate plasticity of auditory system following CI in prelingually severe to profound hearing-impaired children using P1 component of CAEPs and correlate it with auditory perception performance.

MATERIALS AND METHODS

Study Population

Twenty-eight congenitally profoundly hearing-impaired children (15 boys, 13 girls) who received a cochlear implant before the age of 3 years participated in this study. Their mean age at the time of implantation was 21.3 months (range: 18 months to 2 years 9 months). All participants were born to hearing parents and were identified as having hearing loss within the first six-month of life following the implementation of regional hearing screening program (14). All children in the current study were followed longitudinally as part of a comprehensive, "CI-Registry" study at Ahvaz Jundishapur University of Medical Sciences (AJUMS), Iran.

All children had a complete insertion of electrode into the cochlea and have attended regular pre- and post-operative rehabilitation sessions.

The protocol and procedures of this investigation were approved by the Ethics Committee of the AJUMS (Registration number: IR.AJUMS.REC.1396.245) which were in complete accordance with the ethical standards and regulations of human studies of the Helsinki declaration (2014). After the enrollment of the subjects, all of the procedures of this study. The procedures, potential benefits and risks of this study were clearly explained to the parents of the children and after that the written consent forms were obtained from all the parents.

Experimental Procedures

CAEP test

The CAEP assessments was carried out in a sound-treated room using the HEARLab system (National Acoustics Laboratory and Frye Electronics). A single channel electrode montage was utilized for all participants. The active and ground electrodes were placed on vertex (Cz) and forehead (Fz) sites, respectively. The reference electrode was also placed on right or left mastoid. The inter-electrode's impedances were kept <5 kΩ.

The children were evaluated in a comfortable chair, with the speaker adjusted to their head height at one meter away. The stimuli on the HEARLab system (/m/, /g/, and /t/) were extracted from running speech and presented at 65 dB SPL (0.9/s presentation rate; alternating polarity). These vowel-free stimuli were selected because they have a spectral content in the mid-, low-, and high-frequency areas, respectively. The stimulus length for the /m/ and /t/ vowels was 30 msec and for the /g/, 21 msec. The amplitude of P1wave was recorded prior to CI operation and 3-month post-CI.

Categories of Auditory Perception (CAP) test

Auditory perception was assessed with the CAP test, an 8-point hierarchical scale of auditory performance (**Table 1**). The CAP scale ranges from no awareness of environmental sound (category 0) to conversational use of the telephone with a known speaker (category 7) (15).

Statistical analysis

Statistical analyses were performed using the SPSS software (ver. 17.0). The normality of the data was confirmed by Kolmogorov–Smirnov test and then the comparisons were performed using parametric tests. Pair sample t-test was used

Table 2: *The mean P1 amplitude (±SD) before and after cochlear implantation*

Sound Stimulus	P1 amplitude (µ V)		*p-value*
	Pre-CI	3 months after CI	
\m\	0.51 (0.14)	1.09 (0.20)	<0.001
\t\	0.63 (0.29)	1.12 (0.54)	<0.001
\g\	0.65 (0.25)	1.21 (0.35)	<0.001

to compare P1 amplitude during pre- and post-implantation phase of study. The significance level was set as 0.05 for all statistical analyses.

RESULTS

The mean values of P1 amplitude for different speech stimuli at pre-implantation and follow-up period are presented in **Table 2**. Our findings revealed that the mean P1 amplitudes has been increased from pre-CI condition to pre-CI stage for all tested sounds (Paired t-test, $p<0.001$).

The mean CAP scores after 3-month implantation (2.16 ±0.47) significantly improved compared to pre-CI (0.53±0.51) condition (Paired t-test, $p<0.001$).

Pearson's correlational analysis indicated a positive correlation between P1 amplitude and CAP score changes from pre- to post-implantation (r=0.62, $p=0.018$).

No significant differences in the group averages for P1 amplitude were found between the different speech stimuli of /m/, /g/, and /t/ ($p>0.05$). In addition, the present results indicated that the gender had no significant effect with the change in the CAP score ($p=0.091$) and P1 amplitude ($p=.064$) after implantation.

DISCUSSION

Using CAEPs, it is possible to non-invasively determine the maturational status of the auditory cortex in a given subject using various biomarkers. In hearing-impaired children, CAEPs provide a useful tool for assessing whether auditory stimulation via cochlear implantation is appropriate. In addition, these potentials reflect different stages of sensitive periods during which auditory input must be provided. In this article, we recorded the P1 component as a biomarker of primary auditory cortex development in humans. It has been shown that the decrease in P1 latency and increase in P1 amplitude reflect maturational alternations in the auditory cortex, including improved synaptic connections, decreased refractory periods, and improved myelination, much of which initiate as a result of auditory stimulation.

In the present study, we evaluated the development of central auditory maturation (as evidenced by increases in P1 amplitude) in children who received multichannel CIs in early childhood. We found that P1 amplitude revealed significant improvement following 3 months experience of implantation. Kral et al. (16) have demonstrated that congenitally deaf cats show an atypical pattern of activation within the layers of the primary auditory cortex. They reported that early stimulation with a CI leading to a more neural organization within and between cortical layers resulting in robust cortical responses and shorter response latencies across time.

Hearing loss during the first years of life results in sensory deprivation, which in returns prevents normal growth and proper formation of the neural connections essential to form a functional sensory system. Therefore, children with a history of early auditory deprivation reveal structural and functional changes in their auditory system, which in turn influences the results they can obtain using the amplification devices such as cochlear implants.

Sharma et al. recorded CAEPs in congenitally profound hearing-impaired children using multichannel CI devices (age range: 1.3 to 17.5 years) who had at least 6 months of experience with their prosthesis. A comparison of cortical responses in the children using CIs with those of age-matched normal-hearing children showed that subjects with devices who had the longest period of auditory deprivation before CI operation (≥7 years) revealed abnormally late CAEPs, and those who had the shortest period of auditory deprivation (≤3.5 years) demonstrated age-appropriate latency responses (17).

CONCLUSION

The present study evaluated the effects of CI on the reorganization of the cortical auditory system in prelingually deaf children using CAEPs. Moreover, the averaged P1 amplitude showed no significant difference between the different speech stimuli in different assessment intervals. Our findings demonstrated that CI influences the auditory system and CAEP is a reliable method to measure these effects.

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