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RESEARCH ARTICLE

Comparison of sustained auditory attention between children with cochlear implant and normal children

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Abstract

Background and Aim: Cochlear Implants (CIs) bypass a non-functional inner ear by a direct electrical stimulation of the auditory nerve. Compared to normal acoustic hearing, sounds transmitted through the CI are degraded and this electrical signal may change the attention capacity of children with CI. According to Kahneman's model, the presence of CI input might trigger the allocation of limited-capacity central resources for attentional processing of this degraded input and lead to attentional deficiencies. The aim of this study was to compare sustained auditory attention between children with CI and normal children.

Methods: Eighteen children with unilateral CI in right ear and profound hearing loss in left ear with age of implantation under two years, and 40 normal hearing children were selected for this study. The age range of all the children was between 8 and 11 years. Each child in the normal group was tested twice; once binaural and once with left ear plugged. In order to compare sustained auditory attention between the groups, we used sustained auditory attention capacity test (SAACT) and calculated inattention, impulsive, reduction index, and total errors for each child.

Results: In the normal group, all mentioned test variables in binaural versus monaural were not significantly different. In CI group, the values of inattention, impulsive, and total errors were more than these errors in the normal group whether bilateral or unilateral ($p<0.05$).

Conclusion: There is a statistically significant difference in all SAAC test variables (inattention, impulsive, reduction index, and total errors) between normal and implant groups.

Keyword: Cochlear implant; children; sustained auditory attention

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Introduction

The ability to selectively focus on one aspect of the environment and the same time and ignore other aspects is called attention [1]. Attention is an important cognitive process that is necessary for educational purposes [2]. Attention may be characterized by its selectivity and intensity. Selectivity narrows the focus of information processing from a broad range of stimuli, thoughts, and answers, to a simple aspect of the environment, or a selected group of stimulus-response activities. Intensity improves information-processing quality since information processing focus is reduced. As a result, an improvement occurs in the quality of cognitive activities involved in the attention behavior. This last aspect is called sustained attention [3]. One of the most popular ways to assess sustained attention is the continuous performance test (CPT), which requires the individual to keep awake and react to the presence or absence of a target stimulus that has been previously specified. It has numerous presentation methods (auditory, visual, or verbal) [4]. Sustained auditory attention capacity test (SAACT) is a version of CPT originally developed by Feniman et al. for assessment of sustained auditory attention [5]. It is an auditory alertness task that evaluates auditory attention or the ability to listen and respond to auditory stimuli over a long period of time. They showed that SAACT is very helpful for evaluation sustained auditory attention in children. Although there was a significant difference in test scores between different age groups, they did not find any significant difference between genders [5].

Children with cochlear implant (CI) show worse performance on inhibition-concentration and working memory than children with normal hearing with the same age group [6]. In addition, children with CI have attention problems and poor attention in all spectral cues [7] in comparison with normal hearing children. Cochlear implants (CIs) bypass a non-functional inner ear by a direct electrical stimulation of the auditory nerve. Compared to normal acoustic hearing, sounds transmitted through the CI are degraded [8]. The World Health Organization (WHO) estimates that 360 million people in the world have disabling hearing loss [9]. CI is the most successful neural prosthesis to date, with more than 220,000 implanted individuals worldwide in 2011 [10]. Cognitive abilities are strictly limited by quantitative constraints on processing capacity [11]. Until now, it remains unknown how auditory cognition adapts to the degraded input from the CI. Many CI users, however, have trouble with more challenging listening tasks such as speech intelligibility in noise [12]. Kahneman's model assumes a limited-capacity central resource in addition to a separate unit, which is capable of distributing different parts of the central resource over specific tasks [13]. If we apply this idea to CI-mediated hearing and listening, the presence of CI input might trigger the allocation of limited-capacity central resources for attentional processing of this degraded input. Importantly, these central resources would not be allocated to auditory input in normal-hearing (NH) listeners [14]. Prior to the present work, no study has been conducted for evaluating sustained auditory attention behaviorally in children with CI. In the present paper, we compare the capacity of sustained auditory attention between children with CI and 8 to 11 years of age and normal children. We used the Persian version of SAACT, which its reliability and validity had been obtained by Soltanparast et al. [15].

Methods

This study was carried out on 18 children with CI (8 boys and 10 girls) aged 8 to 11 years (mean=9.43 and standard deviation=0.84). The control group consists of 40 normal children (20 girls and 20 boys) at the same age of the test group (mean=9.40 and SD=0.75. For the selection of normal children, we used random sampling between three elementary schools in Tehran, Iran. Purposive sampling technique was used for the test group. The children with CI were selected from reading case history of the file of children implanted at Amir Alam Hospital. To analyze a real function, we compared normal children listening with both ears and children with right ear implanted. For simulating the condition of hearing with one ear in children with CI, we covered the left ear impression and performed the test unilaterally.

The inclusion criteria for children with CI were having the age of implant surgery under 2 years old, education in ordinary schools, having CI in the right ear and a serious hearing loss in the left ear without any hearing aid. The inclusion criteria for normal children were having normal otoscopy results, normal hearing thresholds equal or better than 20 dBHL at octave frequencies

(0.5, 1, 2, 4 KHz) [16], and symmetric average hearing thresholds for both ears. The inclusion criteria for both groups were no history of neurocognitive problems, epilepsy, head trauma, severe fever, ototoxic drug consumption, brain surgery, underlying disease and behavioral problems, being right handed (defined by Edinburgh handedness inventory), age 8 to 10 years, and having a normal IQ. All the participants were monolingual and native Persian speakers. All the children with CI had cochlear nucleus device and CP800 speech processor and used advanced combination encoder (ACE) strategy for processing. The number of active electrodes was 22 intracochlear and 2 extra cochlear for all participants. Children with CI were tested for speech recognition under free field approach and a score >80% was obtained. All participants or their parents signed a printed informed consent form. The study was approved by the Human Research Ethics Committee of Tehran University of Medical Sciences.

Persian version of SAACT (the main version is from Feniman et al. [5]) consists of a list that has 100 words chosen from a list of 21 monosyllabic Persian words. There is a target word in the inventory that is randomly repeated 20 times during each session. Monosyllabic words have been chosen so that they do not resemble the target word [15]. The participants were asked to report when they heard the target word that presented free field (via loudspeaker). For normal children we tested each child twice; once with both ears uncovered (bilaterally) and the other time with left ear covered via impression and muff (unilaterally). The list runs 6 times without interruption that takes about 20 minutes and there are just a few seconds between the runs. The words were played through laptop on a fixed intensity level that was calibrated by the sound level meter to meet 60 dB SPL at the ears.

The decision criteria include inattentive error (i.e. the total frequency with which the target word is not recognized in all six stages of test), impulsiveness error (i.e. the total frequency with which misrecognition of the target word occurs in all six stages of test), attention reduction span index (i.e. the number of correct answers in the sixth stage of the SAACT minus the number of correct answers in the first stage and total score of sustained auditory attention capacity test), and the sum of the total number of inattentive and impulsiveness errors in all six stages [5].

Since the type of the test variables and a number of errors were quantitative and discrete, for comparing normal children with one ear covered and two ears we applied nonparametric Wilcoxon test. Mann-Whitney U test was used to compare test variables between CI and normal group. All tests were applied using SPSS 24 at a statistically significant level (p=0.005). This research has been supported by Tehran University of Medical Sciences grant number 93-04-33-27836.

Results

The SAACT scores in CI children and normal unilateral and bilateral children and group comparison results showed in Table 1. Statistical analysis of data showed a significant difference in all test variables (reduction index, inattention, impulsive and total errors) between CI and normal group (bilateral and unilateral) (p<0.01), this shows that children with CI had more errors than normal children and attention reduction span index was fewer in normal children than children with CI. No statistically significant difference found in test variables between unilateral normal group and bilateral normal group (p>0.05). Comparison results of test variables between two genders are shown in Table 2 (for children with CI and normal hearing children tested bilaterally). As can be seen in Table 2, there is not any difference in all test variables between girl and boys in normal children and children with CI (p>0.05). Comparison of test variables in children with CI and normal hearing children has done between 3 age groups (8-9, 9-10, 10-11). Results of this comparison have shown in Table 3 (children with CI) and Table 4 (normal children) and show not any statistically significant difference between groups neither in Cochlear implantees nor normal children (p>0.05).

Table 1. Median, minimum and maximum of the performance measures for unilateral and bilateral normal group and children with cochlear implant group

	Normal (unilateral)		Normal (bilateral)		Cochlear implant			
	Median	Min-Max	Median	Min-Max	Median	Min-Max	p (NU and CI)	p (NB and CI)
Inattention error	1	0-4	1	0-3	2	0-3	0.002	0.206
Impulsive error	1	0-3	1	0-3	2	0-5	0.002	0.202
Total score	2	0-6	2	1-5	5	1-7	0.000	0.439
Reduction span index	0	0-3	0	0-1	1	0-2	0.001	0.97

NU; normal unilateral; NB; normal bilateral; CI; cochlear implant

Discussion

We aimed to compare the capacity for auditory attention between children with CI and normal children aged 8 to 11 years old. The findings showed a significant difference in all test variables between implanted children with one cochlear device in right ear and children with normal hearing. The findings also showed a better performance and fewer errors in all SAACT variables in normal children than children with CI. In general, this study showed that the presence of early bilateral profound hearing loss can affect continuous auditory attention capacity in children, and even cochlear implantation before 2 years old could not improve this attention in comparison with normal hearing children. The possible reasons for this finding could be auditory deprivation before CI. However, some authors such as Manrique et al. show that when implantation performed before 2 years of age, CI offers a quicker and better improvement of performance without augmenting the complications associated with such an intervention [17]. Moreover, Kral and Sharma also show the optimal time for cochlear implantation is within the first 3.5-4.0 years of life (best before the 2nd year of life), during which the time central auditory pathways show the maximum plasticity to sound stimulus [18]. Unilateral hearing loss of binaural processing is another difference between children with CI and normal children; findings of this study showed no significant difference in auditory attention capacity in normal group between bilateral and unilateral mode, and binaural processing did not make difference in performing the SAACT; but, neuroplasticity probably occurred in unilateral pathways. In this regard, Jiwani et al. investigated cortical responses in 34 adolescents who had over 10 years of unilateral right CI experience, within the first week of bilateral CI activation. The findings showed abnormal recruitment of the left prefrontal cortex (involved in cognition/attention). Thus, using a CI only for one ear for hearing beyond the time domain of cortical maturation makes continuing asymmetries in the auditory system, which needs adding more cortical areas to support hearing and does not completely compensate deprivation of unstimulated pathways [19]. The difference observed in this study in part may be due to deficits in sequencing and cognitive processing. Pre-frontal cortex plays a critical role in learning, planning, and executing sequences of thoughts and actions [20]. Electrophysiological data shows that deaf children compared to hearing peers have decreased cerebral maturation in the left frontotemporal regions and bilateral frontal regions [21]. A lack of auditory input may reduce auditory-frontal connectivity [22], altering the neural organization of the frontal lobe and especially the prefrontal cortex leads to delayed cortical maturation in this region and have significant effects on the development of cognitive and motor sequencing skills used in language and other aspects of cognitive processing [23]. The difference in SAACT test between cochlear implantees and normal children

Table 2. Median, minimum and maximum and p-value of the performance measures for CI children and normal children (bilateral) between two genders

	Cochlear implant					Normal (bilateral)				
	Girl		Boy			Girl		Boy		
	Median	Min-Max	Median	Min-Max	p	Median	Min-Max	Median	Min-Max	p
Inattention error	2	0-3	2	1-3	0.673	1	0-4	1	0-3	0.532
Impulsive error	2	1-5	2	0-3	0.674	1	0-3	1	0-2	0.176
Total score	5	2-7	4	1-6	0.433	0	0-5	3	1-4	0.086
Reduction span index	1	0-2	1	0-1	0.270	2	0-2	0	0-1	0.807

could be because of the degraded signal transmitted from CI. However, CI auditory stimulation facilitates auditory pathway maturation, which decreases the latency of the p1 component and advance the development of auditory and speech skills [24] and plasticity occurs in response to the new signal. SAACT is a new test that is applied in different populations. Mondelli et al. investigated the effects of mild hearing loss on the SAACT scores in a group of 60 children aged 7 to 11 years. They found that mild hearing loss could affect SAACT scores. They also reported that children with the sensorineural hearing loss (SNHL) and conductive hearing loss showed a lower performance according to SAACT results in comparison with the control group and the greatest influence was observed in the presence of SNHL [24]. This difference in SAACT between children with hearing loss and normal children is in confirmation with the claim that degraded signal makes a disturbance in attention. Seidel and Joschko showed that in normal children, continuous performance test results changed with increasing age, although not affected by gender. They also reported data from subjects with attention deficit and hyperactivity disorder and indicated that they perform significantly more poorly than the controls with time on the task. They suggested that the ability to sustain attention increases with age and does not vary between genders [25]. In the present study, there was no difference between two genders in the case of inattentive error, impulsiveness error, attention reduction span index, and a total score of sustained auditory attention capacity test. This finding in accordance with reports of Feniman et al., who performed SAACT on 280

Table 3. Median, minimum, maximum and p-value of the performance measures for children with CI between 3 age groups

	8-9		9-10		10-11		
	Median	Mid-Max	Median	Min-Max	Median	Min-Max	p
Inattention error	1	0-2	0	0-4	1	0-3	0.646
Impulsive error	1	0-3	1	0-2	1	0-3	0.354
Total score	1.5	0-4	2	0-6	2	0-5	0.849
Reduction span index	0	0-1	0	0-1	0	0-1	0.636

Table 4. Median, minimum, maximum and p-value of the performance measures for normal children (bilateral) between 3 age groups

	8-9		9-10		10-11		
	Median	Min-Max	Median	Min-Max	Median	Min-Max	p
Inattention error	2	1-3	2	1-3	2	0-3	0.529
Impulsive error	2	1-3	2	1-3	2	0-5	0.704
Total score	4	2-6	4	3-5	5	1-7	0.760
Reduction span index	1	1-1	1	0-1	1	0-2	0.783

children aged 6 to 11 years (141 boys) and found no difference between two genders in the criteria measured by us [5]. Although we found no significant difference in age groups in the present study, the function of two genders was the same. This contradiction about age groups between the findings of the present study and those of Feniman could be because of smaller sample size in the present study.

Conclusion

Based on the results of this study, it seems that children with CI have a worse performance in all sustained auditory attention capacity test variables than normal children. This result can indicate that even early intervention in deaf children cannot prevent malfunction in sustained auditory attention.

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Conflict of interest

The authors declared no conflicts of interest.

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