Research Article

Enhancing Executive Functioning: The Impact of Cognitive Rehabilitation on Cochlear-Implanted Children

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Citation: Gharashi K, Abdi R. Enhancing Executive Functioning: The Impact of Cognitive Rehabilitation on Cochlear-Implanted Children. Aud Vestib Res. 2025;34(2):?-?.

Article info:
Received: 22 Aug 2024
Revised: 16 Sep 2024
Accepted: 22 Sep 2024

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Short running title: Enhancing Executive Functioning: The Impact…

Highlights:

- Executive Functions (EFs) are essential for learning and self-regulation in children
- Children with hearing impairments face very challenges in EFs and language skills
- Cognitive rehabilitation effectively enhances EFs in children with cochlear implants

ABSTRACT

Background and Aim: Executive Functions (EFs) are essential for learning and self-regulation in children. This study explored the transformative potential of Cognitive Rehabilitation (CR) in enhancing EFs among children with Cochlear Implants (CI). The focus was on assessing key areas of cognitive flexibility, rule acquisition, attention, spatial planning, working memory, and strategy use.

Methods: Utilizing a semi-experimental design with pre-test and post-test evaluations, our study focused on children aged 8 to 11 years. A total of 24 children (13 girls and 11 boys) were randomly assigned to either an experimental or a control group. The experimental group underwent 12 sessions of targeted computerized CR, while the control group received no intervention. Post-intervention, we compared the outcomes of both groups.

Results: The results revealed a significant improvement in the EFs of the experimental group compared to the control group (p=0.01). These findings underscore the effectiveness of CR in enhancing executive functioning in children with CI.

Conclusion: the results of this study showed that cognitive rehabilitation could improve and enhance cognitive flexibility, rule acquisition, attentional set shifting, spatial planning, motor control, working memory capacity, and strategy use.

Keywords: Cognitive rehabilitation; executive functions; deaf children; cochlear implant

Introduction

Executive Functions (EFs) are crucial for human learning, intelligence, and daily performance, particularly in children. These cognitive processes are fundamental to tasks involving self-regulation, strategic planning, cognitive flexibility, and impulse control, all of which are linked to the neural development of the brain's prefrontal cortex [1]. Sensorineural hearing loss caused by diverse environmental and genetic factors is considered as the most prevalent defect in children, frequently encounter significant obstacles in various aspects of their development and well-being [2]. Approximately 2 to 3 out of every 1000 children born in the United States are identified with a detectable level of hearing loss in one or both ears [3]. Children with hearing impairments often miss the critical window for language acquisition, leading to challenges in both language development and executive functioning [4]. Given the persistent and complex nature of hearing loss, these challenges in executive functioning can endure for years, significantly affecting the quality of life and learning outcomes for these children [5].

EFs are associated with the neural development of the brain's prefrontal system, involve self-monitoring processes and cognitive and metacognitive activities, and are responsible for a combination of excellent brain capabilities, inhibition, strategic planning, cognitive flexibility, and impulse control [1]. In children with hearing impairments, underdevelopment in these regions can disrupt both speech-language acquisition and EFs, necessitating early and targeted interventions [6].

Studies have consistently highlighted the importance of EFs skills, such as working memory and cognitive control, for language development. When these cognitive processes are not well-aligned, the need for rehabilitation services becomes critical [7, 8].

Cognitive Rehabilitation (CR) has emerged as a promising approach to enhance EFs by using exercises and targeted stimuli to improve cognitive capacity [9]. Numerous studies have demonstrated the positive effects of CR on information processing speed, attention, cognitive improvement, language skills, and various aspects of executive functioning [10]. However, while CR is widely used in many countries, its application for children with hearing impairments, particularly in Iran, has been relatively overlooked. The study conducted by Beer et al. examined the working memory, inhibition-concentration, and organization-integration skills of two groups of children with Cochlear Implants (CI) and normal hearing. The findings revealed that preschool children with cochlear implants performed significantly weaker in these areas compared to their peers with normal hearing [5]. The research conducted by Bansal on hearing loss indicates that cognitive training can enhance executive function, verbal memory, and attention in recipients of cochlear implants [10]. Mattioli et al. underscored in their study that CR targeting attention, information processing, and executive functions proves to be highly effective for patients with Multiple Sclerosis (MS) who exhibit low levels of disability [11]. Studies conducted by Kesler et al. illuminate the transformative effects of cognitive rehabilitation programs on young children with cancer. a program of computerized cognitive exercises can be successfully implemented at home in young children. These exercises may be effective for improving executive and memory skills in this group, with concurrent changes in neurobiologic status [12]. A comprehensive meta-analysis that studied by Taljaard et al. suggests a compelling link between hearing impairment and cognitive difficulties [13]. The results of Ashori's study revealed that the CR program positively influences the executive functions and emotional regulation of students with hearing impairment, underscoring its transformative potential in enhancing their cognitive abilities [14]. The research conducted by Gharashi and Abdi, demonstrated that CR significantly enhances working memory and planning skills in children with hearing loss [15]. Ultimately, researchers at the Indiana University School of Medicine used various neurocognitive tests to study the performance of children with CIs and children with normal hearing. Compared to children with normal hearing and development, children with CIs exhibited: Smaller immediate memory capacity, Slower verbal rehearsal speed, Slower scanning of short-term memory, Shorter memory spans, delays in EFs, poor sequence learning. These neurocognitive factors were linked to the children's performance on at least one traditional speech-language measure [16].

In the aforementioned investigations, the majority of scholars have explored certain facets of the elements comprising executive functions. However, our focus was on assessing key areas of cognitive flexibility, rule acquisition, attentional set shifting, spatial planning, motor control, working memory capacity, and strategy use. our study prioritized the interests of children engaged in CR activities by incorporating computer-based evaluations. This not only fostered a positive experience but also encouraged active participation in the rehabilitation sessions. The primary instrument utilized in this study was the Cambridge Neuropsychological Test

Automated Battery (CANTAB), a comprehensive cognitive assessment tool developed at Cambridge University in 1980. Chosen for its efficiency, standardized facilities, automatic response recording, and ease of use with children, CANTAB provides a robust evaluation of cognitive functions. Importantly, it assesses executive performance independent of language and cultural differences through five subtests [17]. In fact, our study embraced a holistic approach by selecting all five core components of EFs as the foundation for research hypotheses. This comprehensive investigation allowed us to discuss and analyze the EFs components collectively, providing a more integrated understanding of their roles and interactions. Given the importance of cognitive development in children with hearing impairments and the scarcity of research on the effectiveness of CR in this population, we sought to evaluate the effect of CR on the executive functions of these children Therefore, the present study was conducted to determine the effectiveness of CR and aimed to investigate the effect of CR on EFs of children with CI.

Methods

The present study employed a semi-experimental design featuring pre-and post-tests with both experimental and control groups. The statistical population consisted of hearing-impaired children with cochlear implants, aged 8 to 11 years, who were referred to the Rehabilitation Center for Children with Hearing Disorders in Tabriz, Iran, in 2020. From a total of 200 cochlear-implanted children, a sample of 24 was selected using a purposive sampling method, following coordination with the center's management. Prior to the commencement of the research, the parents of all participants provided their informed consent. To assess the children's cognitive abilities, an intelligence test using the Wechsler scale for children [18] was administered, along with pre-tests related to executive skills utilizing CANTAB software. The subjects were then randomly assigned to either the experimental group (n=12) or the control group (n=12).

After selecting the participants, families in the experimental group received detailed explanations about the study's goals and methods, with a strong emphasis on the anonymity and confidentiality of the participants' information. The treatment protocol was delivered individually by an experienced psychologist over 12 consecutive sessions, each lasting 90 minutes, conducted three times a week for four weeks (as outlined in Table 1). The CR program was based on the hierarchical model developed by Sholberg and Mateer [9] and implemented using the methods of Goldstein and Levin [19]. At the conclusion of the sessions, a post-test was administered to both groups to evaluate the outcomes of the intervention.

Before each test, participants underwent a practice session to familiarize themselves with the procedure. The CANTAB test suite was specifically selected to assess the EFs of children with CI, focusing on tasks that required minimal verbal and non-verbal responses, allowing for quick learning and execution. The inclusion criteria were as follows: a) profound hearing loss in both ears (greater than 90 decibels in the better ear); b) age between 8 and 11 years; c) receipt of CI before the age of 4; d) no other diseases or disabilities; e) normal intelligence, with an IQ between 90 and 110; f) not taking any medication; g) having hearing parents; and h) onset of hearing impairment before language acquisition (before the age of two). Exclusion criteria included: a) withdrawal from the study; b) development of certain diseases during the study period; c) failure of the cochlear implant; and d) missing more than one session of the CR program. The following tests were employed to evaluate the performance of the children with CI participants:

Intra-extra dimensional set shift

The Intra-Extra Dimensional set shift (IED) test assesses rule acquisition and reversal, focusing on visual categorization, attention shifting, and cognitive flexibility. Participants are shown two patterns and must identify the correct one by touching it. As they learn the rule, the computer alters it, requiring them to adapt. The test includes nine stages of increasing difficulty, and children receive immediate feedback. To advance, they must make six consecutive correct choices at each stage. The test ends if a participant fail to learn the rule within 50 trials. The score reflects the number of completed stages, measuring cognitive flexibility.

Spatial working memory

The Spatial Working Memory (SWM) evaluates the ability to remember and manipulate spatial information, detecting impairments in the frontal lobe. Participants search for a hidden token by tapping boxes on the screen. The test measures errors when revisiting a box where a token was already found and strategy when starting a new search. A lower score suggests the use of less effective strategies, providing insights into spatial working memory.

Spatial span

The Spatial Span (SSP), assesses visuospatial memory by showing participants boxes that change color in sequence. The task starts with two boxes and increases in difficulty. Participants must replicate the sequence by tapping the boxes in the correct order. Failure to do so after three tries ends the task, with the final score reflecting the longest sequence completed.

One-touch stockings of Cambridge

The One-Touch Stockings of Cambridge (OTS) test evaluates frontal lobe function by asking participants to calculate the number of moves needed to replicate a pattern of colored balls on the screen, selecting the correct answer from numbered options.

Stockings of Cambridge

The Stockings of Cambridge (SOC) test, based on the Tower of London task, assesses spatial planning and working memory. Participants must move colored balls to match a target configuration within a limited number of moves. The task is scored based on the number of problems solved using the minimum moves [20].

Data analysis

Statistical analysis was performed using SPSS (version17.0). To ensure the validity of covariance assumptions, several statistical tests were employed. The Shapiro-Wilk test was used to verify the normality of the variable distributions, while an independent t-test assessed the homogeneity between the control and experimental groups. The box test evaluated the uniformity of the covariance matrix, and Levene's test was used to check the equality of variances for the dependent variables across the groups. All preliminary conditions were met, confirming the appropriateness of conducting a covariance analysis. The mean scores of EFs in children with CI following the CR intervention were thoroughly examined. To control for underlying factors such as IQ, age at the time of receiving the cochlear implant, and the age at which rehabilitation began, Multivariate analysis of covariance was employed. Statistical significance was set at $p<0.05$ for all comparisons.

Results

Participant demographics and statistical findings

In this study, 24 children with CI, aged 8 to 11 years, participated. The group comprised 13 girls (54%) and 11 boys (46%), with a mean age of 9.62 years in the experimental group (SD=0.98) and 9.23 years in the control group (SD=0.89). All participants had bilateral hearing loss exceeding 90 decibels and were bilingual in Turkish and Persian. The mean IQ of the experimental group was 102.08 (SD=2.84), while the control group had a mean IQ of 102.33 (SD=2.71). The mean age at which participants received their CI was 2.93 years in the experimental group (SD=0.70) and 2.97 years in the control group (SD=0.84) (Table 1).

The results of the means and standard deviations of the pre- and post-test scores for the IED, SSP, SWM, SOC, and OTS tests in both the intervention and control groups indicated that after the intervention, the experimental group demonstrated a significant improvement in the mean scores for IED, SSP, SWM, SOC, and OTS ($p <0.05$). In contrast, the control group did not show any significant changes in their scores.

To evaluate the significance of differences among the EFs assessed, Multivariate analysis of covariance was employed. The probability of erroneously accepting the null hypothesis when comparing post-test scores for IED, SSP, SWM, SOC, OTS between the experimental and control groups was found to be less than 0.001. This result indicates a statistically significant difference between the groups in these cognitive measures after adjusting for pre-test effects ($p=0.034$). Specifically, CR in the experimental group led to marked improvements in IED, SSP, SWM, SOC, and OTS scores ($p=0.001$). This suggests a notable interaction effect among subjects in their post-test scores, even when accounting for pre-test performance. The CR had a significant positive impact on the group effect IED performance, with ($F_{(1,20)}=32.49$, $p\leq0.001$). This suggests that CR effectively improved EFs in children with CI. The group effect also significantly reduced total errors in IED stages completed total errors with an ($F_{(1,20)}=11.35$, $p\leq0.003$). SWM between search errors: the CR intervention significantly reduced between search errors, shown by an ($F_{(1,20)}=12.12$, $p\leq0.002$), there was also a notable improvement in SWM strategy indicated by an ($F_{(1,20)}=8.08$, $p\leq0.001$). The CR significantly improved SSP performance, with an ($F_{(1,20)}=30.44$, $p\leq0.001$).

For total errors in SSP stages completed, the effect was even stronger, with an ($F_{(1,20)}$=194.89, p≤0.001) indicating substantial improvement. The group effect on OTS showed a significant improvement with an ($F_{(1,19)}$=16.13, p≤0.001) highlighting enhanced problem-solving skills. The CR had an impressive effect on SOC performance, with an ($F_{(1,19)}$=85.41, p≤0.001) suggesting that the intervention greatly improved children's ability to solve complex problems .High effect sizes were observed for SSP stages completed (0.90) and SOC (0.81), suggesting that CR had a substantial impact on these EFs. Other areas like IED (0.61) and OTS (0.45) also showed meaningful effects. In summary, the results demonstrate that CR significantly enhances EFs in children with CI across various tasks, particularly in flexibility, memory, problem-solving, and strategy use. The strong statistical significance and high effect sizes indicate that CR is an effective intervention for improving EFs in this population. This analysis not only highlights the effectiveness of CR but also underscores its potential to make a meaningful difference in the lives of children facing cognitive challenges.

Discussion

The purpose of this study was to explore the impact of CR on the EFs of children with CI. The findings revealed a significant improvement in the post-test scores of EFs in the experimental group, while no notable changes were observed in the control group. These results confirm the hypotheses that CR positively influences EFs (IED, OTS, SOC, SSP, SWM) in children with CI.

By implementing a CR program and analyzing the results before and after the intervention, it became evident that CR can enhance EFs in children with CI. Given the close relationship between language development and EFs [5], the negative impact of hearing impairment on speech, language development, and EF-related challenges can be mitigated through CR interventions [21]. However, caution is needed when extending these findings to other groups of children with CI, as various factors may contribute to EF difficulties.

The results align with previous research by Beer et al., which compared EF skills in children with CI to those of children with normal hearing [5]. The findings also resonate with studies by Mattioli et al [11], who demonstrated the significant effect of CR on information processing speed, attention, and EFs in patients with multiple sclerosis, and Ashori, who examined effect of cognitive rehabilitation program based on memory on executive functions and cognitive emotion regulation in children with hearing impairment [14]. Taljaard et al [13] also reported similar results in their study on the negative impact of hearing loss on cognition, highlighting the relationship between hearing loss and EF deficits.

This study marks the first systematic review of the effectiveness of a CR program tailored specifically for children with CI. The advantages of this approach stem from its ease of implementation, access to standardized facilities, and the automatic recording of responses.

Concentration and attention is one of the most important components of executive functions, which is more important in children, especially children with hearing impairment, as shown in the results of this study, the significant difference in IED scores in the intervention group and the control group can indicate that the exercises CR creates changes in children's focus and attention change, so that CI children can strengthen the task of attention change and cognitive flexibility, in fact, IED evaluates the ability to adapt a person's thinking to new and unexpected conditions and It allows participants to switch their attention between different stimuli or tasks and measures how well they can shift their focus and adjust their responses to changing rules or demands. These assignments increase attention and cognitive flexibility in children and are very important for effective problem solving and adaptation to new situations in daily life [10]. In order to explain this issue, it can be said that in order to strengthen the concentration and cognitive flexibility in children with hearing impairment, various methods and exercises can be used that help to improve their cognitive and listening skills. The most important of them are listening exercises, cognitive games, and movement activities, and the use of experimental tools. In fact, in this study, by emphasizing these educational points, in addition to increasing children's interest, changes were made in their attention and concentration. and assesses a person's ability to adapt their thinking and behavior in response to changing rules, which is essential for effective decision making and cognitive control [20].

Moreover, the significant differences observed in the average SWM scores before and after the cognitive rehabilitation intervention suggest that these variations can be attributed to effective methods aimed at strengthening working memory in children. These methods include engaging memory games, brain exercises, creating a structured environment, utilizing reminder tools, encouraging children to seek help, and incorporating visual games. Together, these strategies play a crucial role in enhancing children's working memory and preparing them for more effective learning experiences. considering that OTS is responsible for evaluating spatial planning and memory, the difference in the average scores of this test before and after the intervention in CI children can indicate that CR has a positive effect on spatial planning and memory. In fact, The OTS requires individuals to visualize the solution and plan their moves strategically, thereby testing their spatial reasoning and working memory capabilities.

On the other hand, SOC is another spatial planning test that measures the function of the frontal lobe and emphasizes problem solving strategies, thus evaluating spatial planning skills and motor control. Considering the significance of the difference in the mean SOC scores two groups, it can be said that CR has had a positive effect on the ability of CI children to solve problems [20].

In the fifth hypothesis, in order to check the significance of the working memory capacity in the experimental and control groups, we used SSP, considering the significant difference in the average scores of the two groups, it seems that CR has been effective in increasing the working memory of cochlear implanted children. The SSP tests working memory capacity by requiring participants to recall and reproduce sequences of spatial locations. This work includes providing a sequence of places in a network that the participant must remember and repeat in the correct order. In fact, SSP evaluates the capacity and ability to store location information in working memory [5].

The effectiveness of CR can be attributed to its focus on EF components, which, by enhancing memory capacity, likely led to changes in the activity of the frontal lobe, parietal regions, basal ganglia, and the density of dopamine receptors. Due to the neuroplasticity of the networks involved in memory, improvements in daily activities and EFs were observed [15, 16]. It's important to note that EF challenges in children with hearing impairments may not solely result from the hearing impairment itself but also from language delays caused by the impairment. The CR intervention helped expand EF skills in the experimental group compared to the control group, underscoring the significant difference in EF scores between the two groups. By increasing EF capacity, the negative effects of language delay in these children can be mitigated.

Pediatric hearing loss, especially profound congenital hearing loss, disrupts the normal development and function of the auditory system and nerve [2]. This, combined with the lack of timely auditory development, affects brain plasticity and organization, leading to deficits in short-term memory and working memory [16]. The significant differences in EF scores post-intervention suggest that the CR program, with its emphasis on developing frontal, parietal, and basal ganglia-related centers, positively impacted children with CI [8]. Cognitive adaptation in children with CI appears to play an active role in enhancing brain self-regulation, thereby improving behavior regulation. This approach boosts EF capacity by providing targeted stimuli and training, which, in turn, enhances communication language and auditory processing due to the interconnectedness of relevant brain centers. On the other hand, the increase in independence and abilities of disabled adolescents makes them interested in engaging in educational and rehabilitation activities, thereby enhancing their motivation to complete tasks [22]. Therefore, based on the data from this research, it seems that cognitive rehabilitation, by educating and encouraging children to perform cognitive tasks, creates the conditions for improving their cognitive skills and increasing their motivation. This interest and motivation, in turn, naturally draws children's attention to completing more tasks.

Finally, the study highlights the broader implications of hearing impairment and the uncertainty surrounding how best to support cochlear implant development in young children. Hearing impairment can adversely affect a wide range of neurological and cognitive systems, speech perception, and language skills, posing significant challenges to cognitive development. Children with CI are particularly at risk for delays in areas of EFs, such as inhibition, concentration, and working memory dynamics, which are vital for language, learning, and daily functioning. CR interventions offer a potential solution by enhancing active memory, inhibition, concentration, and verbal communication in these children.

Increasing the capacity of EF components allows many cognitive skills and communications to be processed more efficiently in the brain, leading to better development through experience and practice [16]. Therefore, if the gap between the onset of hearing loss and rehabilitation interventions with cochlear implantation is minimized, the development of cognitive functions will be significantly enhanced due to the strong relationship between EFs (such as attention, working memory, control, and inhibition) and the development of spoken language and auditory processing. This highlights the importance of CR.

It should be noted, however, that this study faced certain limitations. The CR intervention was conducted only on children with CI aged 8–11 years, making it challenging to generalize the results to other populations. Additionally, the lack of follow-up was a limitation, as access to these children for further monitoring was not feasible. Future studies should explore the effects of CR interventions on other groups of children with CI to determine the generalizability of these findings. Such research could facilitate the identification of specific disorders in children with hearing impairments and pave the way for timely interventions. While EFs encompass a broad range of cognitive functions primarily regulated by the Prefrontal Cortex (PFC), other posterior and subcortical regions also play critical roles, particularly in integrating information and emotions. Further research is needed to better understand the involvement of subcortical regions in EF regulation.

Deficits in EFs can significantly hinder a person's ability to return to work, school, and social activities. Understanding the adverse effects of EF impairments is crucial for accurate diagnosis and the development of appropriate rehabilitation programs to help children with hearing impairments achieve independent living. Although our understanding of EFs is still evolving, longitudinal studies investigating the impact of EF deficiencies following hearing impairment and the effects of CR on EF rehabilitation have provided valuable insights and paved the way for more effective support for these children.

Conclusion

Cognitive Rehabilitation (CR) intervention in children with Cochlear Implants (CI) can increase the ability of EFs-related components. According to the results of this study, it can be inferred that the independent variable of this study, namely CR intervention, has been able to improve the capacity of executive functions in children with CI aged 8–11 years.

Ethical Considerations

Compliance with ethical guidelines

This study was approved by the Ethics Committee of the Islamic Azad University of Iran with code IR.IAU.TABRIZ.REC.1399.0151 written consent was obtained from the parents of all children participating in the study. After completing the research and knowing the results, the control group also underwent a CR program.

Funding

This article is extracted from the postdoctoral project of Azarbaijan Shahid Madani University with contract number 218.D.30095. These funding sources had no involvement in study design, collection, analysis and interpretation of data, report writing or decision to submit for publication.

Authors' contributions

KG: Study design, acquisition of data, interpretation of the results, statistical analysis, and drafting the manuscript; RA: Study design, interpretation of the results, and drafting the manuscript.

Conflict of interest

The authors declare that they have no conflict of interest.

Acknowledgments

This article is extracted from the postdoctoral project of Azarbaijan Shahid Madani University. The support of Azarbaijan Shahid Madani University, Iran, and the management of the Imam Reza Rehabilitation Center are especially appreciated. The families of children with CI are also acknowledged because of their cooperation in this research.

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Table 1. The contents of cognitive rehabilitation program sessions

Session	Context of sessions
1	Communicating and acquainting children with cognitive methods and exercises, providing explanations of cognitive rehabilitation.
2	Reminiscing exercise of the previous session (getting feedback from the previous session), attention exercises including listening to the rhythm of hearing aids (numbers, words, sentences).
3	Providing explanations of cognitive rehabilitation, attention and concentration exercises including attention retention, increase the skills of attention elements.
4	Teaching concentration and attention tasks including visual, visual, numerical, shapes, letters and memory exercises (selective attention and attention processing exercises).
5	Attention and memory change exercises and comprehension exercises.
6	Teaching homework in descending and ascending order to maintain attention and read an article to understand the content and simultaneously search for pre-determined letters, words and meanings.
7	Auditory, visual memory exercises according to the content of numbers and letters, words, shapes, sentences and logical memory.
8	Verbal, visual memory tasks, making couple associations and verbal organization.
9	EFs exercises include considering a simple task and expressing mental plans with its signs. Mentoring exercises, memory strengthening training (illustration) are other exercises in this session.
10	EFs exercises including classification, differentiation and problem solving and self-instruction in problem solving.
11	Motor memory exercises and motor instructions (one-step to multi-step).
12	Preparing the subject for the exit phase of the CR training program and reviewing the cognitive exercises of attention, memory and EFs.

EFs; executive functions, CR; cognitive rehabilitation

Table 2. Demographic characteristics and descriptive statistics for experimental and control participants

Variable	Category	Experimental group (n=12)	Control group (n=12)	p
Sex	**Female**	5(42%)	6(50%)	0.747
	Male	7(58%)	6(50%)	
Age	**Mean(SD)**	9.42(0.13)	9.71(0.22)	0.319
Hearing threshold levels	**dB**	<90	<90	
Age of cochlear implant	**Mean(SD)**	2.93(0.70)	2.97(0.84)	0.914
IQ	**Mean(SD)**	102.08(2.84)	102.33(2.71)	0.827
Age of intervention	**Mean(SD)**	13.33(7.57)	19.08(8.37)	0.092