Research Article

Investigating the Effect of Persian Phonemic Synthesis Program in Cochlear Implant Users with Phoneme Processing Dificulities

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Citation: Hasanalifard M, Saeedi M, Ajalloueyan M, Abolghasemi R, Shomeil Shushtari S, Amizadeh M. Investigating the Effect of Persian Phonemic Synthesis Program in Cochlear Implant Users with Phoneme Processing Dificulities. Aud Vestib Res. 2024;33(1):47-56.

https://doi.org/10.18502/avr.v33i1.14274

Highlights

- APD is independent of peripheral hearing loss and can be seen in CI users
- The main reason of auditory processing problems in CI users is the DEC deficit
- Auditory processing rehabilitation improves phonological abilities in CI users

Article info:
Received: 30 May 2023
Revised: 18 Aug 2023
Accepted: 18 Aug 2023

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ABSTRACT

Background and Aim: Children with severe to profound sensory-neural hearing loss who use a hearing aid or a Cochlear Implant (CI) are likely to have Decoding (DEC) problems. Various studies recommend auditory processing training to improve auditory processing difficulties in CI users. The aim of the present study was to evaluate phoneme processing difficulties in CI users and to investigate the efficacy of the Persian version of the Phonemic Synthesis Program (P-PSP) in improving phonological abilities in this population.

Methods: A total of 28 prelingually hearing-impaired children aged 8–12 who underwent unilateral (right ear) cochlear implantation were included in this study. They were divided into experimental and control groups. The P-PSP was implemented on the experimental group, and the results were analyzed over three phases: baseline, intervention, and follow-up.

Results: The present study's results indicate that P-PSP training is suitable for CI children, particularly for the DEC subcategory. Moreover, the Persian Phonemic Synthesis Test (P-PST) results significantly improved after the intervention phase compared to the baseline evaluations ($p<0.05$). There was no significant difference between the intervention and follow-up phases' results ($p>0.05$), indicating no recurrence of auditory processing difficulties after discontinuing training.

Conclusion: Based on the study's findings, the Persian version of PSP enhances phonological processing abilities in CI users. Therefore, the use of auditory phonological training in post-implantation rehabilitation programs appears to be highly important.

Keywords: Auditory processing; decoding disorder; cochlear implant; auditory training

Introduction

Auditory and speech comprehension difficulties are considered an important challenge in children with Cochlear Implant (CI). Despite significant advances in surgical procedures, technology, and CI rehabilitation techniques, the functional effects of these advances are not observed in some functions, such as complex functions of auditory processing, reading, writing and etc. [1]. Several studies have shown that individuals with peripheral hearing loss who use hearing aid or CI, can also have central auditory processing problems [2, 3]. Therefore, it can be said that auditory processing disorder is independent of peripheral hearing loss [4]. Indeed, peripheral hearing loss can directly or indirectly lead to auditory processing difficulties [2, 5, 6].

According to different studies, auditory perceptual difficulties in CI users are due to the insufficient capacity of the central auditory system to process a large amount of new sounds over a broad frequency range of hearing and weakness in sub-categories such as Decoding (DEC) and phoneme processing [7, 8]. Based on several studies, the main reason for auditory processing problems in CI users is the DEC deficit which is exclusively related to the auditory cortex [2, 9]. Decoding is the most fundamental category of Buffalo battery for communication and academic functions [10]. Prelingually deaf children with CI who show DEC problems are unable to process speech accurately and swiftly [10]. In many CI users, even after two years following cochlear implantation, some auditory processing abilities remain unresolved, which can be due to the presence of auditory processing disorder before cochlear implantation or the difference in the nature of the received signal before and after cochlear implantation [6, 11, 12]. Generally, abnormal temporal processing ability, reduced speed of speech processing and difficulty in understanding speech in the presence of noise are considered the most important central symptoms in CI users [13].

Currently, Auditory Verbal Therapy (AVT) is considered as one of the most common and well-known rehabilitation methods in cochlear implant centers. The AVT focuses on developing listening skills and spoken language using the auditory signal [14]. Based on several studies, the AVT program improves linguistic skills and auditory comprehension in children with CI [15-18].

However, many CI users show auditory processing problems and poor phonological skills, even after the implementation of rehabilitation programs. This is due to the inadequacy and weakness of these methods in improving phonological abilities.

It seems that in order to improve speech production and temporal processing abilities in children with CI, it is necessary to implement specific therapeutic strategies for the central auditory system. Phonemic Training Program (PTP) and Phonemic Synthesis Program (PSP) are two valuable trainings for treatment of the DEC type of Auditory Processing Disorder (APD).

The PTP is a simple procedure that asks the child to point to a card on which the appropriate sound is represented. The purpose of PTP is changing the child's perception of the sounds and improvement of child's phonemic abilities. When the child shows an acceptable performance on PTP, PSP training can be implemented [3].

The PSP is a training method for DEC deficit and improving the ability to combine phonemes and produce words. The PSP was first introduced by Katz [3]. The main goal of PSP is to gradually change false or ambiguous strategies that seem to be stored in the auditory cortex of the temporal lobe [3]. Other features of the PSP include the ease of administration at different ages with varied cognitive condition, effective in those with profound APD and performable in those with peripheral hearing loss [19].

One of the most important causes of auditory comprehension difficulties and speech production disabilities in CI users is the presence of auditory processing disorder. Therefore, it is necessary to perform appropriate trainings for auditory processing in this population.

Considering the high importance of achieving the maximum benefits of cochlear implants, this study was designed to evaluate phonological processing abilities and to investigate the effectiveness of phonemic synthesis training in CI users.

Methods

Participants

A total of 28 prelingually deaf children (16 girls and 12 boys) aged 8–12 years with a mean age of 9.82 (±1.38) who underwent unilateral (right ear) cochlear implantation were included in this study. All children received a multichannel CI (Cochlear Ltd. Australia) and were implanted in Kerman CI center and one of the CI centers in Tehran. All patients were programmed with the Advanced Combination Encoder (ACE) sound coding strategy.

Thirteen children (8 girls) who had completed Persian Phonemic Training Program (P-PTP) sessions and received the conventional package of CI center (including multi-session programming, auditory training, and speech therapy sessions) were placed in the experimental group. Fifteen children (8 girls) who received only the conventional package of the CI center were included in the control group. Importantly, the control group did not receive any special auditory processing rehabilitation.

All children were right-handed (based on the Edinburgh Hand Dominance Questionnaire), monolingual (Persian speaking), and had a normal IQ (based on the Wechsler IQ test). According to the medical history, all children had severe to profound hearing loss (without any history of mental or neurological problems) and were implanted at the age of 2–3 years. Also, post-implantation sound-field hearing thresholds of all children were less than 35 dB SPL at octave frequencies between 250 and 4000 Hz. All children had participated in speech therapy and received the AVT program after implantation and were completely familiar with the phonemes of the Persian language. Importantly, all experimental children have passed at least eight P-PTP sessions and showed an acceptable performance in the Persian Phonemic Recognition Test (P-PRT).

Research design

This study was an interventional study with a randomized controlled trials design. All participants fulfilled certain inclusion criteria and, based on the random number table, each child was assigned a number from 1 to 28 and was randomly placed in the experimental or control group.

The experimental group received the Persian Phonemic Synthesis Program (P-PSP) and the conventional package of the CI center. The control group received only the conventional package of the CI center without receiving the P-PTP and P-PSP trainings. Data were collected over three phases: baseline, intervention (rehabilitation), and follow-up.

Baseline

The baseline phase was performed before the intervention. In this phase, the patient›s performance was evaluated continuously and at specific intervals, without providing any rehabilitation. The purpose of this phase was to compare the results with the intervention and follow-up phases. The data were collected through the P-PRT [20], Persian Phonemic Synthesis Test (P-PST) [21], Speech in Quiet (SIQ) [3] and the Persian phoneme error analysis (P-PEA) form [2, 19, 22]. Eight baseline sessions in which the tests were conducted were performed for each child twice a week. Also, equivalent test lists were used to prevent the learning effect.

Intervention phase

After ensuring a constant trend in the baseline assessment results, therapeutic intervention was implemented for children who met inclusion criteria. The rehabilitation program was designed based on the results of the P-PEA form. First, the number of phonemic errors for each child was determined. Then, according to the P-PEA form, phonemes that were omitted, the number of errors in each phoneme, and added letters were recorded and analyzed.

The rehabilitation sessions lasted about 4 months, and according to the child's condition, at least a total of 15 rehabilitation sessions were implemented for each child in the experimental group. Each session lasted about 30 to 45 minutes. In order to check the improvement process of the child during the training sessions, after the end of each two rehabilitation sessions, the baseline tests were performed for each child and the scores were recorded. After completing the training program and achieving an acceptable level of stability in the results, the training program was stopped and the child was ready to enter the follow-up phase.

Follow-up phase

The main goal of the follow-up phase was to check the stability of the results and the steadiness of the rehabilitation program. In this phase, all baseline assessments were performed twice a week, without administering any effective therapies on the child's auditory processing abilities. The protocol used for scoring and interpreting the results was similar to the two previous phases. Eight follow-up sessions were conducted for each child. All evaluations were the same as in the first and second phases.

Tests and procedures

Persian phonemic synthesis test

The PST assesses a child's ability to blend sounds into a word. This test is considered one of the most important diagnostic methods for DEC deficit [10]. The PST can be used as a valuable instrument to evaluate the effectiveness of the PSP in CI users [3]. The test consists of 25 words and the number of phonemes in each word varies from 2 to 4.

The P-PST was developed by Negin et al. [21]. The scoring of this test is based on the interpretation of quantitative and qualitative indicators. The qualitative indicators include: delay (X), extreme delay (XX), quick response (Q), quiet rehearsal (QR), non-fused response (NF), reversal (R), preservation (P), and omission of the first letter (1st). Accurate interpretation of qualifiers is very important in designing the best rehabilitation protocol.

The quantitative score is calculated based on the number of correct responses and ranges from 0 to 25. The qualitative score is calculated by subtracting the number of X, XX, Q, and QR errors from the quantitative score and can vary in the range of 0 to 25. Both qualitative and quantitative scores evaluate the DEC category [3].

Also, the qualitative indicators of the P-PST were investigated in this study based on the Buffalo model. For this purpose, the errors of X, XX, Q, QR, NF, R, P, and 1st were carefully examined and recorded if they occurred. Then, each of these errors was divided into three subcategories of DEC, TFM, and ORG [3].

Persian phoneme recognition test

The PRT is a method designed by Katz for evaluating auditory processing ability at the phoneme level, specifically in CI users [3]. This test is considered as a valuable tool to assess the efficacy of the PTP [3].

The P-PRT was developed by Shomeil Shushtari et al. and was normalized in individuals aged 7 years. The P-PRT contains 56 items. The child was required to repeat the phoneme up to 5 seconds after presenting each phoneme. The scoring of the P-PRT was based on the percentage of correct answers.

Persian phonemic errors analysis

Given that phonemes are a crucial aspect of auditory processing, the PEA is considered an important factor for designing the rehabilitation program and determining the person's status following therapy [23]. In 2017, the P-PEA was developed by Negin et al. [21] and Barootiyan et al. [19]. The P-PEA was used in this study for three purposes: categorizing the child's problems, attaining a personalized training protocol, and evaluating the effect of the training. Most of the phonemic indicators are on the PST. The PEA contains three phonemic errors including Omission (OMM), Addition (ADD), and Substitution (SUB).

Therapies

Persian phonemic synthesis program

The P-PSP was developed and then evaluated by Barootiyan et al. [19]. Generally, there are 15 lessons in the PSP, and by moving from the 1st lesson to the 15th lesson, there is a gradual increase in the number of phonemes (e.g. 3 to 4) in the words and in the difficulty level of the child's task. This program starts with two or three choice response picture plates in the first three lessons to ensure that all children can participate in the program.

The first lesson started with two very simple pictures, whose letters were presented sound by sound, and the child had to point to the desired picture. Then the next two pictures were shown and this process was repeated. At the end, all pictures were repeated again to ensure that the child has learned all sounds and words of the first lesson. Lesson 2 was conducted in the same way, with the difference that the child's choice was in the form of three options and with three images.

Lesson 3 started like lesson 2 with the presentation of three pictures, but at the end, the child had to repeat the desired word without the help of pictures. The subsequent lessons were verbal without pictures. The score of each lesson was recorded on the P-PSP summary sheet. The summary sheet was used to monitor the child's performance on the P-PSP. This enabled us to evaluate the pattern of child's progress.

Data analysis

Data analysis was conducted using SPSS 17. Descriptive statistics were applied for P-PST scores, errors based on the Buffalo model (DEC, TFM, and ORG), and P-PEA errors (SUB, OMM, ADD, and total). The Kolmogorov-Smirnov test was used to check the normality distribution. The data distributions did not follow a normal curve ($p<0.05$). Therefore, the Wilcoxon and Mann-Whitney tests were used to compare the scores before and after training, and between the experimental and control groups, respectively.

Results

Persian phonemic synthesis test

The mean, SD, median, minimum, and maximum of the quantitative and qualitative scores of the P-PST and errors related to the DEC, TFM, and ORG subcategories in the experimental group during the baseline, intervention, and follow-up phases are presented in Table 1. As is clear, all indicators have improved in the intervention phase compared to the baseline.

Table 2 shows statistical indicators related to the quantitative and qualitative scores of the P-PST and errors related to the DEC, TFM, and ORG subcategories in the control group before and after receiving the conventional package of the CI center. Also, the quantitative and qualitative scores and DEC, TFM, and ORG subcategories in the experimental group were compared between intervention and baseline phases as well as the intervention and follow-up phases based on the Wilcoxon test. All scores and errors have improved significantly after training ($p<0.05$). Also, there was no significant difference between the results of the intervention and follow-up phases ($p>0.05$), which is an indicator of the stability of the treatment effect.

Table 1. Statistical indicators of the scores of Persian phonemic synthesis test in the experimental group during the baseline, intervention and fallow up phases

Statistic		Quant	Qual	DEC	TFM	ORG
Mean(SD)	Baseline	6.846(5.444)	3.230(2.385)	12.769(3.086)	8.153(2.409)	2.153(1.068)
	Intervention	18.307(3.794)	14.923(2.431)	4.000(1.224)	3.000(1.290)	0.923(0.862)
	Fallow up	17.153(3.362)	15.384(2.292)	3.538(1.330)	2.307(1.031)	1.000(0.671)
Median	Baseline	7	3	12	8	2
	Intervention	19	15	4	3	1
	Fallow up	17	19	3	2	1
Minimum	Baseline	0	0	8	4	0
	Intervention	12	10	2	0	0
	Fallow up	13	11	2	1	0
Maximum	Baseline	17	7	18	12	4
	Intervention	23	18	6	5	2
	Fallow up	23	17	5	5	0

Quant; quantitative, Qual; qualitative, DEC; decoding, TFM; tolerance fading memory, ORG; organization

A comparison of the quantitative and qualitative scores and also DEC, TFM, and ORG subcategories in the control group was made before and after receiving the conventional package of the CI center based on the Wilcoxon test. No significant changes were detected for any of the scores before and after receiving the conventional package of the CI center (p>0.05).

Also, the performance of experimental and control groups in terms of quantitative and qualitative scores and errors based on Buffalo sub-categories were compared using the Mann-Whitney test. In the baseline phase, no significant difference was seen between the performances of the two groups (p>0.05). However, after intervention phase, a significant improvement was seen in the experimental group compared to the control group (p<0.05). Only in the ORG error there was no significant difference between the performance of two groups (p>0.05), which can be due to the nature of PSP in treatment of DEC and TFM disorders. Generally, in this study, prevalence of ORG error was very low in both groups.

Table 2. Statistical indicators of the scores of Persian phonemic synthesis test in the control group before and after receiving the conventional package of the cochlear implant center

Statistic		Quant	Qual	DEC	TFM	ORG
Mean(SD)	Before	6.466(4.206)	3.266(2.120)	14.133(2.669)	8.600(2.414)	1.400(1.502)
	After	7.933(3.432)	5.466(2.748)	12(3.047)	7.733(2.344)	1.741 (0.883)
Median	Before	6	4	14	8	1
	After	7	6	12	8	0
Minimum	Before	0	0	10	5	0
	After	3	1	7	4	0
Maximum	Before	15	6	18	14	4
	After	14	10	19	11	2

Quant; quantitative, Qual; qualitative, DEC; decoding, TFM; tolerance fading memory, ORG; organization

Table 3. Statistical indicators of phonemic errors based on phoneme error analysis form in the experimental group during the baseline, intervention and fallow up phases

Statistic		ADD	OMM	SUB	Total
Mean(SD)	Baseline	14.076(4.405)	21.153(4.616)	17.461(6.319)	52.153(7.690)
	Intervention	4.615(1.894)	7.327(2.121)	4.076(1.977)	15.692(3.750)
	Fallow up	5.307(2.010)	5.765(1.875)	6.124(2.401)	13.538(3.126)
Median	Baseline	14	22	16	52
	Intervention	4	7	4	15
	Fallow up	6	5	6	17
Minimum	Baseline	5	14	7	38
	Intervention	2	4	2	10
	Fallow up	2	3	4	8
Maximum	Baseline	21	31	28	64
	Intervention	8	11	10	23
	Fallow up	7	9	8	20

ADD; added, OMM; omission, SUB; substitution

Table 4. Statistical indicators of phonemic errors based on phoneme error analysis form in the control group before and after receiving the conventional package of the CI center

Statistic		ADD	OMM	SUB	Total
Mean(SD)	Before	19.933(4.113)	20.933(5.725)	16.147(4.050)	58(9.219)
	After	16.800(4.345)	18.866(5.316)	17.133(3.907)	51.800(9.843)
Median	Before	19	20	17	57
	After	18	20	16	52
Minimum	Before	13	14	11	45
	After	9	10	10	36
Maximum	Before	27	31	27	73
	After	25	29	23	67

ADD; added, OMM; omission, SUB; substitution

Patient's errors based on Persian phonemic error analysis

The mean, SD, median, minimum, and maximum of the patient's scores of the P-PEA form in the experimental and control groups are shown in Tables 3 and 4 respectively. Also, the number of phonemic errors between intervention and baseline phases as well as the intervention and follow-up phases in the experimental group were compared based on the Wilcoxon test. Importantly, all phonemic errors have decreased significantly in the intervention phase compared to the baseline ($p<0.05$). Also, the number of errors in the follow-up phase did not show a significant difference compared to the intervention phase ($p>0.05$).

The comparison of phonemic errors in the control group before and after receiving the conventional package of the CI center was made based on the Wilcoxon test. No significant change was found for any of the errors before and after receiving the conventional package of the CI center ($p>0.05$).

The results of comparison of control and experimental groups for phonemic errors using the Mann-Whitney test showed no significant difference between two groups in the baseline phase ($p>0.05$). However, regarding the intervention phase, there was a significant difference in the number of errors ($p<0.05$), with the experimental group posting remarkably lower mean errors.

Discussion

The purpose of this study was to evaluate the effectiveness of the P-PSP in improving the phonemic synthesis ability in Persian-speaking children with CI. Given that the PTP always precedes the PSP, it was first ensured that all children had completed the P-PTP sessions before entering the study. After ensuring the child's sufficient skill on P-PTP, the P-PSP was administrated. To check the effectiveness of P-PSP, P-PST and P-PEA were used.

The PEA is indeed considered one of the best methods for analyzing a patient's phonological errors. As various studies have shown, the majority of prelingually deaf children face many challenges in understanding speech, and these challenges often stem from the occurrence of various phonological errors [24-27]. In this study, the P-PEA has been utilized to determine the common pattern of phonological errors and to design a suitable and personalized rehabilitation program for each child. This approach is crucial in addressing the unique needs of each child and ensuring they receive the most effective treatment possible.

After implementation the P-PSP, quantitative and qualitative scores of the P-PST were improved significantly. Importantly, a significant improvement was observed in the DEC and TFM sub-categories (especially DEC). Finally, upon entering the fallow up phase, there was no difference between the quantitative and qualitative scores. Also, the trend of changes in the fallow up phase showed no significant changes in both scores after stopping the training.

Regarding the P-PST indices in the experimental group after intervention, the mean was 18.30 and 14.92

for quantitative and qualitative scores respectively, which is indicative of effective training based on Table 1. In these two scores, the performance of all children showed significant improvement after training. Regarding the qualitative errors in the DEC, TFM and ORG subcategories, the number of errors decreased significantly after intervention which is indicative of strong effect of training based on Wilcoxon test. With regard to the P-PEA, the most common phoneme errors that were seen in this study included SUB and OMI. According to the P-PEA, the training had strong effect in SUB, ADD and OMM errors. These findings are in agreement with the study conducted by Barootiyan et al. [19]. It was shown a significant decrease in phoneme errors as well as DEC and TFM after P-PSP training.

Katz states that the PSP is an integral part of DEC treatment and its benefits are clearly seen in phonics, reading, writing and speech perception [3]. This is in accordance with the findings of this study which showed a reduction of DEC errors after P-PSP therapy in all children.

Another deficit that may be seen in CI users is TFM and disorders related to memory [3]. One of the abilities of auditory processing that is included in the TFM category is short-term auditory memory. In this study, in all samples, the errors occurred in the TFM category were significantly reduced after P-PSP therapy. This finding is in line with the study conducted by Luria who reported that the PSP, is an important factor for improving phonemic active memory.

It is worth mentioning that the most common category in this study was the DEC deficit. In the studies conducted by Katz [3], DEC was mentioned as the most common type of APD in CI users, which is in line with this study. Also based on his findings, TFM is the second most common APD in CI users [3]. This has also been observed in this study, as the prevalence of TFM was higher than ORG, which is due to its close link with DEC.

The number of errors related to the ORG was very few in this study. It seems that in the CI users, the main cause of the ORG error is the inability to process phonemes. This inability leads to an additional load on the auditory processing system and ultimately leads to the loss of the correct phonetic sequence in the formation of words.

In this study, all investigated indicators have improved after training and this improvement was more obvious in children who showed more problems. In other words, the effectiveness of training showed an inverse relationship with the level of difficulties. Indeed, children with more severe auditory processing disorder who showed more DEC and TFM errors on baseline assessments had a better response to training. This finding is in agreement with the study conducted by Katz who reported that children with more severe problems show a better and more obvious response to training [3].

In general, the P-PSP is a suitable training for CI users with phonological problems and it is recommended to be added to rehabilitation protocols after implantation.

Conclusion

This study confirms the existence of phoneme processing difficulties in Cochlear Implant (CI) users. The findings showed that in spite of rehabilitation programs after cochlear implantation, phoneme processing difficulties are clearly seen in CI users. Based on different studies, insufficient phoneme processing and storing of ambiguous information in the brain are two contributing factors for auditory processing difficulties in CI users. However, with the implementation of auditory processing rehabilitation, a significant improvement was seen in phonological processing ability in this population. This finding demonstrated the necessity and importance of phoneme-based rehabilitation programs after cochlear implantation.

Ethical Considerations

Compliance with ethical guidelines

In the present study, all ethical considerations recommended by the Baqiyatallah University of Medical Sciences which approved the study with the Ethical Code of IR.BMSU.BAQ.REC. 1402.037. Also, Participation in the study was based on obtaining informed consent from all parents.

Funding

This research did not receive any grant from funding agencies in the public, commercial, or non-profit sectors.

Authors' contributions

MH, MS, and MA: Study design, acquisition of data, interpretation of the results, statistical analysis, and drafting the manuscript; RA: Study design, statistical analysis, and drafting the manuscript; SSS, and MA: Interpretation of the results and drafting the manuscript.

Conflict of interest

No potential conflict of interest relevant to this article was reported.

Acknowledgments

We also sincerely thank the parents of children for participating in the rehabilitation sessions.

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