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Original Article (Pages: 14914-14928)

Evaluating the Efficacy of Phonemic Rehabilitations in Cochlear Implant Users: A Single Subject Study

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Abstract

Background: In many cochlear implant users, even after some time following cochlear implantation and adequate central auditory stimulation, certain hearing processing capabilities remain unresolved. These difficulties for cochlear implant users have a very similar manifestation to the decoding sub-category of the buffalo model of auditory processing which has a direct role in accurate phoneme processing. The present study was designed to investigate phoneme processing abilities in cochlear implant users and to evaluate the efficacy of phonemic rehabilitations in this population.

Methods: This was an interventional study with single subject design. Six prelingually deaf children aged between 8 and 11 years were recruited in the study. The performance of the cochlear implant users during three phases of baseline, intervention and follow-up was investigated. Phonemic Training and Phonemic Synthesis programs were administered and the outcomes were compared based on performance of the children in phoneme recognition test, phonemic synthesis test and the phoneme error analysis form.

Results: All findings demonstrated that test scores improved in all six cases after intervention in comparison to the baseline (p< .00).

Conclusions: This study suggests that phoneme-based rehabilitation strategies improve the performance of deaf children with cochlear implants and should be used in postoperative therapy batteries.

Key Words: Cochlear implant, Phoneme recognition, Phonemic Synthesis, Phonemic Synthesis Program, Phonemic training Program.

* Please cite this article as: Shomeil Shushtari S, Fatahi F, Rouhbakhsh N, Saki N, Jalaie S, Negin E, Tavakoli M, karimi M. Evaluating the Efficacy of Phonemic Rehabilitations in Cochlear Implant Users: A Single Subject Study. Int J Pediatr 2021; 9 (12):14914-14928. DOI: **10.22038/IJP.2020.49905.3982**

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Received date: Jun.26,2020; Accepted date:Nov.8,2020

1- INTRODUCTION

The acquisition of phonological processing skills is a challenge for cochlear implant (CI) users. Several studies have shown that despite the effectiveness of CI in restoring audition in individuals with severe and profound deafness (1), the temporal and frequency information provided by CIs is not as detailed as the information delivered by the inner ear. Several studies have reported that auditory processing difficulties are independent of hearing thresholds and this can be seen in users of hearing aids or CIs (1, 2). Katz (2009) reported that some of the auditory processing skills do not improve even after two years of CI use. It was reported that temporal processing, Gap in Noise (GIN) detection, phonological awareness, spelling, speech in noise are impaired in CI users (3). Katz reported that auditory processing difficulties in cochlear implant users have a very similar manifestation to the decoding (DEC) subcategory of the buffalo model of auditory processing (4). In many cochlear implant users, even after some time following cochlear implantation and adequate central auditory stimulation, certain hearing processing capabilities remain unresolved, which may be due to preimplantation impairment (5-7). The decoding is defined as rapid and accurate processing of speech, especially at the phonemic level (8). A common feature of patients with decoding deficits seems to be that vague or incorrect phonological information is stored in their brains (9). The part of the auditory system that is most affected by decoding deficits is the auditory cortex in the middle-posterior part of the temporal lobe (10). Based on Luria's findings, decoding ability is used to discriminate, memorize, analyze, and synthesize the phonemes; and improper functioning in these skills is impaired in the primary auditory cortex of the left hemisphere. Moreover, cochlear implant users have lower speech processing speeds; this could be due to the brain's insufficient capacity to process large amounts of new sounds over a wide range of frequencies (3). Several studies reported that in order to improve hearing processing capabilities in cochlear implant users, individualized rehabilitation programs should be used in this field (6, 11, 12). It seems that one of the most important causes of speech impediment in cochlear implant users could be auditory processing difficulties, and in many cases, this will not be resolved until the users are provided with appropriate treatments for auditory processing. Therefore, due to the importance of achieving the maximum efficiency of cochlear implants, the present study was designed to investigate phoneme processing abilities in cochlear implant users and to evaluate the efficacy of phonemic rehabilitations in this population.

2- METHODS

2-1. Participants

Six prelingually deaf children aged between 8 and 11 years, without contralateral hearing aids, who underwent unilateral (Right) cochlear implantation were recruited in this investigation. All patients received a multichannel cochlear implant (Cochlear Ltd., Australia), and they were implanted at Ahvaz Cochlear implant center, Ahvaz, Iran. All subjects were programmed with the same speech coding strategy ACE (Advanced combination encoder). According to their medical records, none of the deaf children with CIs had any other known physical, neurological or intellectual disability. All children were born from hearing parents with Farsi as their native language. The etiology of deafness was either unknown (n = 5) or viral infection (n = 1). All subjects were right-handed according to the Edinburgh scale (13) (scoring +100). The communication method was the spoken language only for all participants.

Importantly, all children had regular postoperative speech-therapy and auditory training sessions. Details of the demographic information are provided in **Table 1**. Parents were previously informed and signed a written consent form.

Pre-testing was completed before the participants began baseline measures, as described in a subsequent section. Behavioral tests of (central) auditory processing disorder were administered in a sound-treated room with a clinical audiometer (Inventis-Piano), which was calibrated to 1000Hz calibration before the test administration. The recorded stimuli were presented at the most comfortable level (MCL) and delivered through a loudspeaker positioned at 90 cm away from the right side of the child. The Persian Phoneme Recognition Test (P-PRT), the Persian Phonemic Synthesis Test (P-PST) (14) and the Word Recognition Score (WRS) were administered and were scored as criteria for the inclusion.

2-2. Research Design

This was an interventional study with single-subject withdrawal design. The performance of the CI users during different phases of the investigation was examined. The participants, themselves, served as their control group, thus allowing researchers to measure significant changes in performance at the individual level. Single subject designs are effective in determining the effectiveness of specific treatment techniques for individual patients and are critical for the development and implementation of evidence-based practice in communication sciences and disorders (15). Data were collected over three phases of baseline, intervention, and follow-up.

2-3. Baseline phase

The baseline phase was performed before the intervention. The baseline data were used to establish a benchmark against which the individual’s test performance in the treatment and follow-up phases could be compared. The data were collected through P-PRT, P-PST, WRS and the Persian Phoneme Analysis (P-PEA) form. Eight baseline sessions, in which the tests were administered, were recruited for each individual twice a week. All assessments were performed for each individual on a specific day and time throughout the study and the baseline phase lasted 4 weeks. Equivalent test lists were used to prevent the learning effect. Prior to each session, the accuracy of the cochlear implant prosthesis was verified. Furthermore, in all sessions, a fixed protocol was used in scoring, testing and equipment.

2-4. Intervention phase

After ensuring the constant trend of the baseline evaluation results, subjects entered the intervention phase. The therapy program was designed based on the results of the PEA form. A total of 16 therapy sessions were performed on each subject, which took approximately 8 weeks. All tests were the same as the baseline phase. Assessments of the intervention phase were administered once a week (per two sessions of therapy) on the same day and time of the baseline phase. During the therapy, if the child was tired or inattentive, adequate rest periods were provided. Also, at the beginning of all therapy sessions, the integrity of the CI was ensured. Each therapy session took between 25 and 55 minutes, depending on the type and stage of the therapy program. After completing the therapy program and achieving an acceptable level of stability in the test scores, the therapy program was stopped and the patient was prepared to enter the follow-up phase.

2-5. Follow-up phase

In the follow-up phase, all baseline phase assessments were carried out twice a week without providing any effective therapies on the patient's auditory processing skills, to assess treatment stability. In all sessions, a fixed protocol was used in scoring, testing, and equipment. Also, the integrity of the CI was ensured before the start of each session. Eight follow-up sessions were performed for four weeks. All tests were the same as the two previous phases.

2-6. Tests and procedures

2-6-1. Persian Phoneme Recognition Test (P-PRT)

In 1996 and 1997, Katz et al. developed and introduced the PRT for examining phoneme perception. The PRT was developed to investigate phoneme perception abilities, specifically in the cochlear implant users (16). In 2020, Shomeyl et al. (17) developed the Persian version of the PRT establishing the normative data in individuals from 7 years of age to adults. The methods used to administer the P-PRT in the current study were similar to the original study. Fifty-six items (28 phonemes repeated at least once) were used in the P-PRT. Participants were required to repeat the phoneme they heard within a 5 second interval following the presentation of each phoneme. Performance on the P-PRT was computed on the basis of the percentage of correctly recalled phonemes.

2-6-2. Persian Phonemic Synthesis Test (P-PST)

The Phonemic Synthesis Test (PST) was first developed in 1981 by Katz and Harmon (18). The purpose of this test was to see if the listener could blend the individual phonemes that were presented producing the correct/expected word. The test consists of 25 test items along with three instructional items and two items for the children’s familiarity. The Persian version of PST was developed by Negin et al. (14), and the normative data were established in children aged between 7 and 11 years. Test administration and scoring methods in the current study were similar to the main study. Participants were required to listen to the presented phonemes, blend them to form a word and then utter the correct answer after hearing a beep during a 5 second interval. The P-PST has a multi-dimensional scoring method including quantitative and qualitative scores and the qualifiers. Performance on the P-PST was computed on the basis of the correctly formed words (quantitative score) and the effect of qualifiers on correct responses (qualitative score). For more information on the scoring methods of the P-PST see Negin et al. (14).

2-7. Phoneme Error Analysis (PEA)

The Phoneme Error Analysis was used in this study for two purposes; achieving a tailor-made individualized therapy program and recording the effect of therapies on the patterns of phoneme errors. The PEA was introduced by Katz (2009) in the Buffalo model of auditory processing. The PEA is created based on the person’s test performance (3). As reported by Katz in 2016 (19), "using PEA gives us a pretty good idea of which sounds are poorly processed and what the phonemic confusions are and this is much more informative than counting how many of the words were missed on each of the tests". PEA consists of three different phoneme error patterns including substitution, omission and addition.

2-8. Therapies

Two phonemic therapy programs were administered in this research: The Phonemic Training Program and Phonemic Synthesis program used in the Buffalo model of auditory processing. They are designed to enhance the decoding (DEC) capabilities which are directly involved in phoneme processing. All therapies were delivered through a loudspeaker positioned 90 cm away from the right ear of the child.

2-8-1. Persian Phonemic Training Program (P-PTP)

The most basic therapy procedure in the Buffalo model is the Phonemic Training Program (PTP) which was introduced by Katz and Cohen (20). The Persian version of PTP (P-PTP) was developed and then evaluated by Negin et al. (21). As reported by Negin et al. (2018) the P-PTP is recruited as follows; "in the first session, the participant was taught four new phonemes. In the second session, there was a brief review (BR) of the four previous phonemes, and then four new ones were introduced at the end of the session. In the third session, there was a BR of the four phonemes in the second session, then eight phonemes from the first and second sessions were put together and a general review (GR) was conducted and finally, four new phonemes were introduced. This process was followed in the same way (21). This phonemic training program is quick, easy, very effective, and appears to be long lasting (8). For more information see Katz and Cohen (19), Katz (2009) (3), and Negin et al. (21).

2-8-2. Persian Phonemic Synthesis Program (P-PSP)

The second decoding therapy in the Buffalo model of auditory processing is the Phonemic Synthesis program. The PSP was first introduced by Katz and Harmon (18). The aim of PSP is to gradually change the patients' perception of phonemes, to support PTP, and to move the process ahead by connecting sounds to words. The Persian version of PSP (P-PSP) was developed and then evaluated by Barootiyan et al. (22). In this program individual phonemes are presented and the trainees are expected to say the words they form. In the lessons there is a gradual increase in the number of phonemes (e.g. 3 to 4) in the words, in the difficulty level of the phonemes, or in the introduction of consonant blends (8). The P-PSP consists of 15 lessons. For more information see Katz and Harmon (18) and Barootiyan et al. (22).

2-9. Data Analysis

Two methods were used to analyze the collected data including the C-Statistic and the percentage of all non-overlapping data (PAND). The C-statistic as a simple method of time-series analysis can be used to quantify the effectiveness of a treatment. Initially, the baseline data are evaluated and if there was no significant trend in the baseline data, the combination of baseline and treatment data are evaluated again with C-statistic to see if the changes are significant. The C statistic produces a z value, which is interpreted using the normal probability table for z scores. PAND is a method to establish the effect size of the treatment and closely related Pearson's Phi. The procedure is conducted through calculation of the total number of data points that do not overlap between baseline and intervention phases. According to Ma (2006), effect sizes range from 0 to 1; 0.9 to 1 reflects highly effective treatment, 0.7 to 0.9 reflects moderately effective treatment, and less than 0.7 reflects no effective treatment (23).

3- RESULTS

3-1. Persian Phoneme Recognition Test (P-PRT)

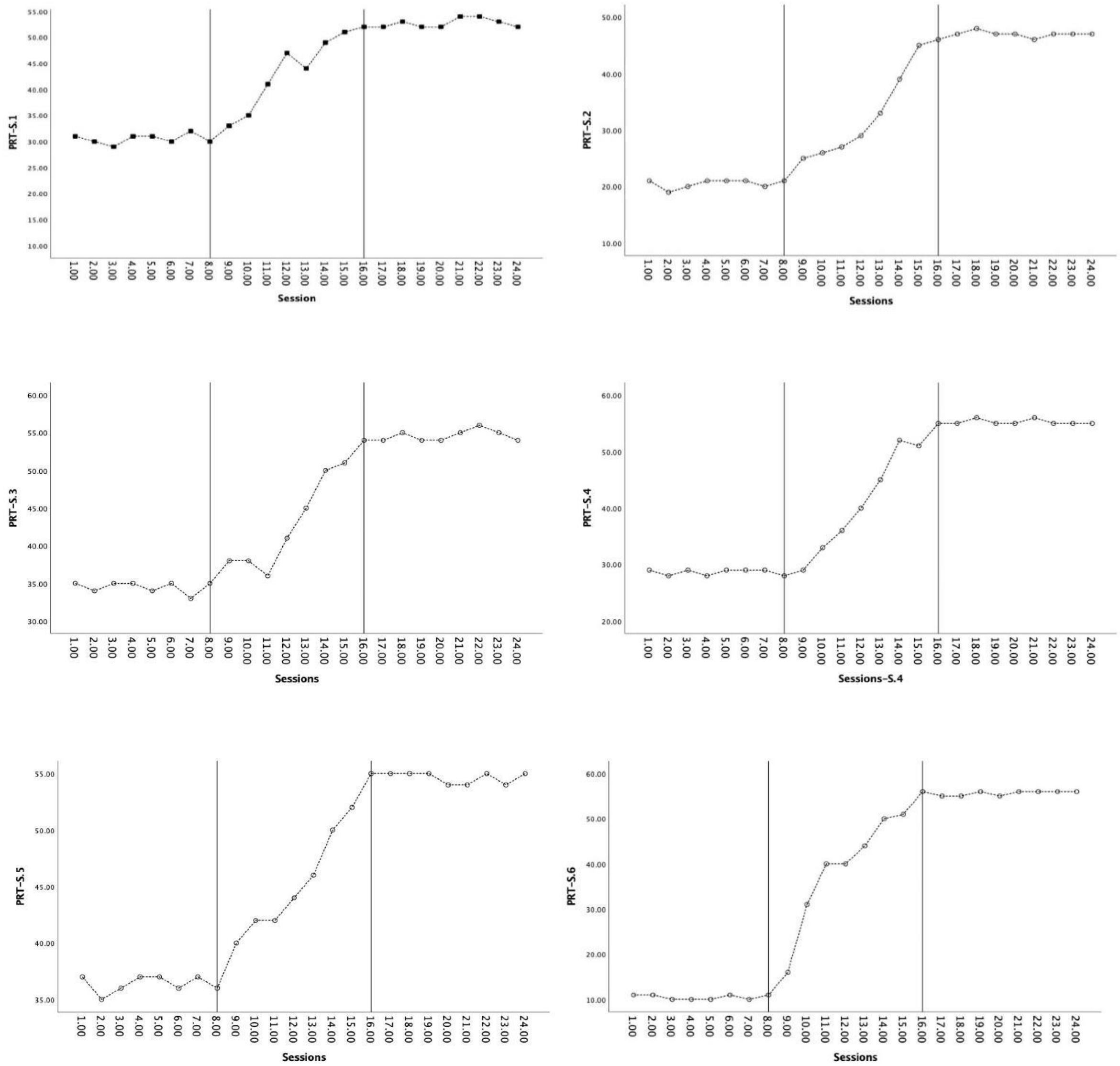
The demographic and cochlear implant properties of the patients are presented in **table 1**. Etiology of hearing loss was unknown among the six patients aged between 8-11 years. Two patients were male and four patients were female.

The P-PRT was scored on the basis of the percentage of correctly recalled phonemes. **Fig .1** shows the percentage of correctly recalled phonemes on the P-PRT during the baseline, intervention, and follow-up phases for each of the six CI users.

Table-1: Demographic and cochlear implant properties of the samples

Subject	Age (year)	Gender	Age of implantation (month)	Number of therapy sessions post-CI	Etiology of HL	Active electrodes
S1	9	F	41	100	Unknown	22
S2	8	M	23	300	Unknown	22
S3	10	M	22	270	Unknown	22
S4	11	F	21	250	Unknown	22
S5	9	F	35	150	Unknown	22
S6	8	F	24	100	Infection	22

CI: Cochlear Implant, F: Female, M: Male, S: Subject, HL: Hearing Loss



S.: Subject, PRT: Phoneme Recognition Test

Fig. 1: The trend of performance in Phoneme recognition test for each of the six cochlear implant users

Tables 2, 3, and **4** show the findings of the C-statistic method for each of the six CI users. No significant change could be found for any of the six participants in the baseline phase for Persian phoneme recognition test, Persian phonemic synthesis test for all six subjects and Persian phoneme error analysis form for all six subjects. However, all six participants showed evidence of significant improvements on the P-PRT with the addition of intervention phase. Effect size was evaluated on the basis of PAND.

Table 5 shows the findings of effect size for each of the six CI users. The effect size evaluation in P-PRT confirmed the treatment to be highly effective for all six CI users.

Table-2: The comparison of baseline and intervention phases based on C-statistics in Persian Phoneme Recognition Test for all six subjects

Subject	Phase	Statistic		
		C	Z	P value
S1	Baseline	-0.25	-0.81	0.41
	Baseline & Intervention	0.93	17.08	< 0.001
S2	Baseline	0	0	1
	Baseline & Intervention	0.95	17.33	< 0.001
S3	Baseline	-0.5	-1.62	0.10
	Baseline & Intervention	0.93	17.02	< 0.001
S4	Baseline	-0.33	-1.08	0.14
	Baseline & Intervention	0.95	17.43	< 0.001
S5	Baseline	-0.16	-0.52	0.30
	Baseline & Intervention	0.95	17.36	< 0.001
S6	Baseline	0	0	1
	Baseline & Intervention	0.96	17.48	< 0.001

S: Subject, C: C-Statistics, Z: Z- Statistics

Table-3: The comparison of baseline and intervention phases based on C-statistics in Persian Phonemic Synthesis Test for all six subjects

Subject	Phase	Quantitative Score			Qualitative Score		
		Statistics			Statistics		
		C	Z	P value	C	Z	P value
S1	Baseline	-0.12	0.41	0.68	0	0	1
	Baseline & Intervention	0.92	16.93	< 0.001	0.95	17.38	< 0.001
S2	Baseline	N/A	N/A	N/A	N/A	N/A	N/A
	Baseline & Intervention	0.96	17.52	< 0.001	0.95	17.43	< 0.001
S3	Baseline	-0.12	0.41	0.68	-0.33	-1.08	0.28
	Baseline & Intervention	0.94	17.19	< 0.001	0.96	17.50	< 0.001
S4	Baseline	0.33	1.08	0.14	-0.60	-1.08	0.14
	Baseline & Intervention	0.94	17.28	< 0.001	0.94	17.16	< 0.001
S5	Baseline	0.33	1.08	0.14	-0.6	-1.08	0.14
	Baseline & Intervention	0.95	17.40	< 0.001	0.96	17.57	< 0.001
S6	Baseline	N/A	N/A	N/A	N/A	N/A	N/A
	Baseline & Intervention	0.96	17.58	< 0.001	0.96	17.57	< 0.001

S: Subject, C: C-Statistics, Z: Z- Statistics, N/A: Not available

Table-4: The comparison of baseline and intervention phases based on C-statistics in Persian Phoneme Error Analysis form for all six subjects

Subject	Phase	Omission			Substitution			Added		
		Statistics			Statistics			Statistics		
		C	Z	P value	C	Z	P value	C	Z	P value
S1	Baseline	-0.07	-0.25	0.80	0.12	0.40	0.68	0.44	1.43	0.15
	Baseline & Intervention	0.93	17.00	< 0.001	0.95	17.38	< 0.001	0.93	17.07	< 0.001
S2	Baseline	0	0	1	-0.33	-1.08	0.28	-0.33	-1.08	0.15
	Baseline & Intervention	0.92	16.79	< 0.001	0.95	17.41	< 0.001	0.96	17.48	< 0.001
S3	Baseline	-0.66	-0.21	0.83	0.12	0.40	0.68	0.47	1.54	0.12
	Baseline & Intervention	0.96	17.56	< 0.001	0.96	17.50	< 0.001	0.95	17.36	< 0.001
S4	Baseline	0	0	1	-0.01	-0.03	0.48	-0.33	-1.08	-.14
	Baseline & Intervention	0.95	17.34	< 0.001	0.95	17.44	< 0.001	0.94	17.22	< 0.001
S5	Baseline	0.20	0.64	0.52	0.13	0.42	0.67	0	0	1
	Baseline & Intervention	0.95	17.34	< 0.001	0.96	17.57	< 0.001	0.88	16.11	< 0.001
S6	Baseline	-0.33	-1.08	0.28	0.20	0.64	0.52	0.56	1.82	0.68
	Baseline & Intervention	0.75	13.66	< 0.001	0.85	15.49	< 0.001	0.90	16.42	< 0.001

S: Subject, C: C-Statistics, Z: Z- Statistics

Table-5: The results of Effect Size in all six subjects based on PAND analysis in all three tests

Subject	P-PRT	P-PST (Quant.)	P-PST (Qual.)	PEA (Omission)	PEA (Substitution)	PEA (Added)
S1	100%	81.25%	100%	93.75%	87.5%	93.75%
S2	100%	100%	100%	100%	93.75%	100%
S3	100%	87.5%	100%	100%	100%	100%
S4	93.75%	93.75%	93.75%	100%	100%	100%
S5	100%	100%	100%	100%	100%	100%
S6	100%	100%	100%	100%	100%	100%

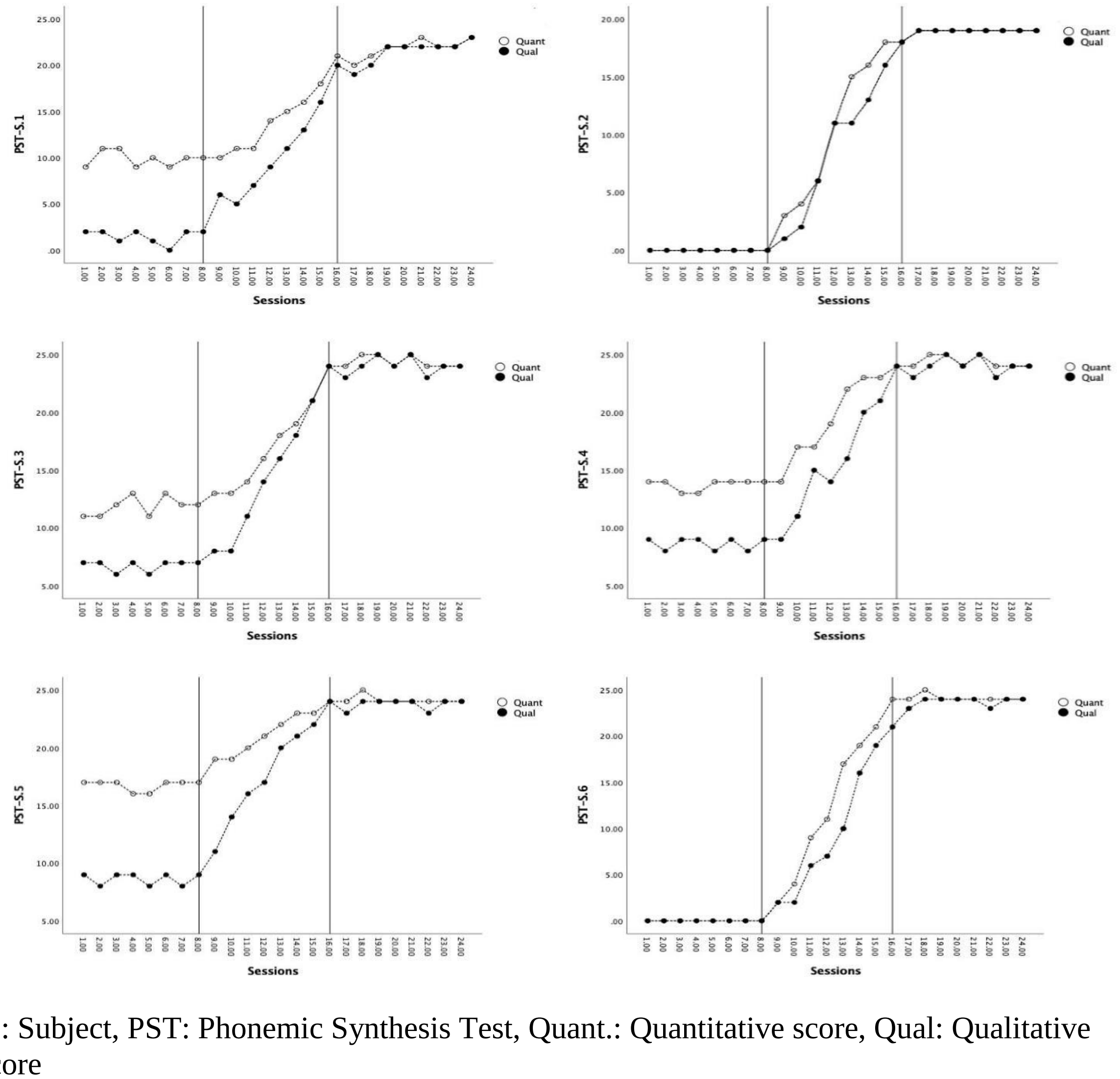
S: Subject, PAND: percentage of all non-overlapping data, P-PRT: Persian Phoneme Recognition Test, P-PST: Persian Phonemic Synthesis Test, Quant.: Quantitative score, Qual.: Qualitative score, PEA: Phoneme Error Analysis form

3-2. Persian Phonemic Synthesis Test (P-PST)

Both the quantitative and qualitative scores were calculated to determine the results of the P-PST. **Fig. 2** shows the performance trend in the P-PST during the baseline, intervention, and follow-up phases for each of the six CI users. **Table 3** shows the findings of the C-statistic method for each of the six CI users.

No significant change could be seen in any of the six participants in the baseline phase. Subjects S2 and S6 were not able to respond to any of the 25 items of the P-PST. Therefore, due to the floor effect, c-statistics could not be computed for these subjects in the baseline phase.

However, all six participants showed evidence of significant improvements on both the Quantitative and Qualitative scores of P-PST with the addition of intervention phase. Effect size was evaluated on the basis of PAND. **Table 5** shows the findings of effect size for each of the six CI users. The effect size evaluation for the Quantitative scores reflected highly effective treatment for subjects S2, S4, S5, and S6. Also, the findings of effect size for S1 and S3 reflected the moderately effective treatment in the Quantitative scores. The effect size evaluation for the Qualitative scores reflected highly effective treatment for all six CI users.

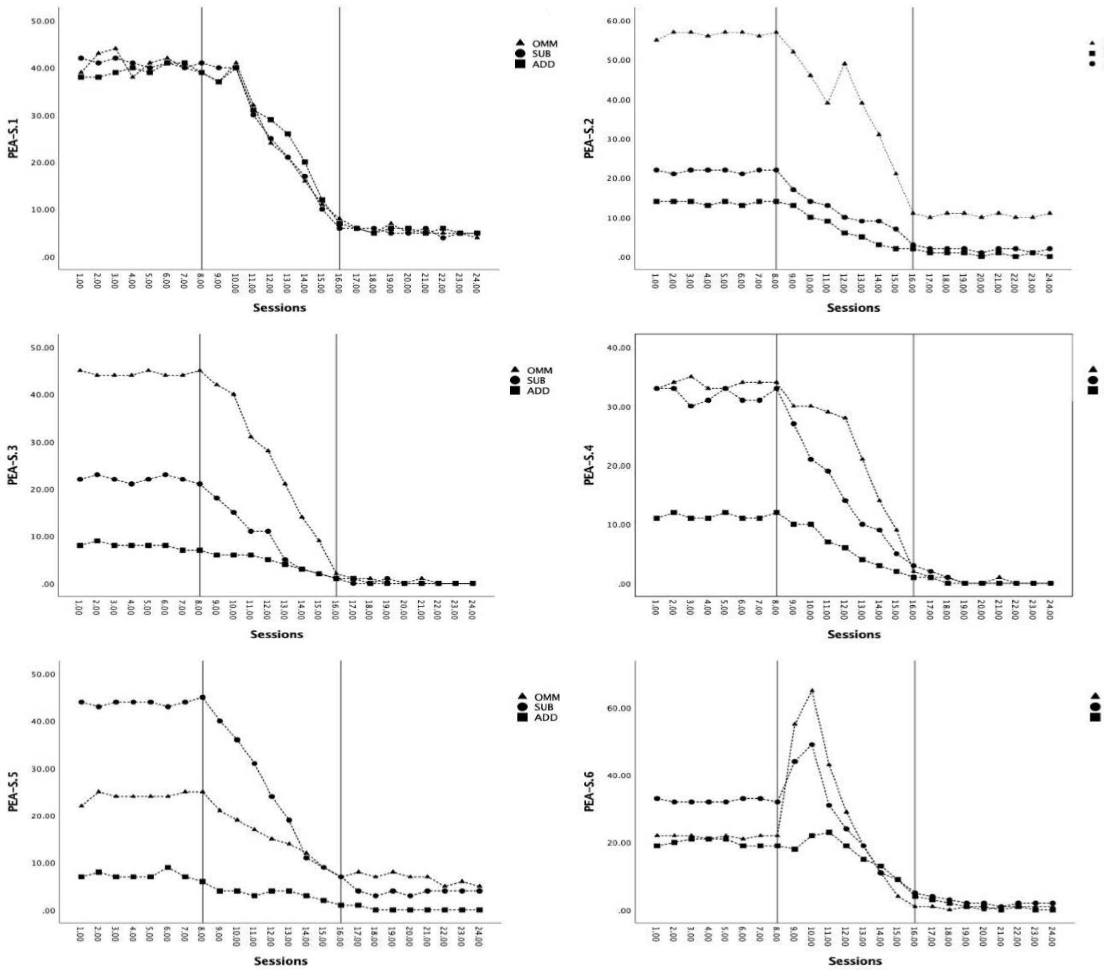


S.: Subject, PST: Phonemic Synthesis Test, Quant.: Quantitative score, Qual: Qualitative score

Figure 2: The trend of performance in Phonemic Synthesis test for each of six cochlear implant users

3-3. Phoneme Error Analysis (PEA)

Analysis of phoneme errors was carried out by examining the phonemic error patterns which had occurred in the P-PRT and P-PST tests. **Figure 3** shows the performance trend in the three patterns of phoneme errors during the baseline, intervention, and follow-up phases for each of the six CI users. **Table 4** shows the findings of the C-statistic method for each of the six CI users. No significant changes could be detected for any of the six participants in the baseline phase for any of the error patterns. However, all six participants showed evidence of significant improvement in all three phoneme error patterns with the addition of intervention phase. Effect size was evaluated on the basis of PAND. **Table 5** demonstrates the findings of effect size for each of the six CI users. The effect size evaluation in all three error patterns reflected highly effective treatment for all six CI users, except for the substitution pattern in S1, which was reflected as moderately effective treatment. As shown in the trends of performance, there was no evidence to prove the recurrence of the disorder after elimination of therapies. Therefore, the treatment was stable in all aspects.



S.: Subject, PEA: Phoneme Error Analysis, OMM: Omission error, SUB: Substitution error, ADD: Added error

Figure 3: The trend of performance in Phoneme error analysis for each of the six cochlear implant users

4- DISCUSSION

In the present study, by using a single-subject study design, we examined the effects of phonemic training and phonemic synthesis programs on phonological abilities and skills of prelingually deaf CI users. We used P-PRT, P-PST and PEA scores as a baseline to compare the results before and after the treatment. The findings revealed that there was no spontaneous improvement in the performance of the participants during baseline phase. However, with introducing the interventions the performance of all six subjects improved significantly based on C-statistics ($p < .00$). Also, the findings of effect size revealed ES between 81.25% and 100% based on PAND analysis. This finding revealed a proper to decisive intervention.

Simon et al. (2019) reported that the information provided by cochlear implant in the fields of spectral, frequency, and temporal information resources is not as accurate as the information that the inner ear provides in normal hearing, and this could lead to distortion in auditory signals. Due to poor signals delivered to the auditory cortex, it is more difficult for CI users to recognize and manipulate the phonological structure of words. In other words, when proper information about the phonemic structure of words does not reach the cortex, the next steps of phonemic processing, that are more complex, will not be performed properly (24). This has also been observed in the current study, as in most subjects, after the completion of the phonemic training program and entering the phonemic synthesis program (which often occurs in the first two to three sessions of phase B), the first scoring jumps are seen in the phoneme recognition test. During the PTP, the phonemes are taught one by one to the patient so that the cortex becomes familiar with the correct processing of each phoneme and it is ready for more complex phonemic processes such as phonemic synthesis to be entered.

Ching et al. (2001) reported that after activating hearing devices such as cochlear implants and hearing aids, the user begins to receive sounds that have not been heard or misheard before. It was reported that distortion due to amplification and noise leads to changes in the audition of language sounds. The findings of the current study suggest that the auditory processing difficulties at the level of phonemic processing are impaired in CI users (25). These findings are in line with the previous studies of Katz (1998, 2009), who stated that the auditory processing abilities are not intact in CI users even after a period of CI usage as long as two years (3, 16). The P-PRT results show that cochlear implant users have difficulty, even in simple phoneme recognition tasks. Also, the findings of the P-PST results show that CI users have difficulty in phonemic synthesis tasks. Tests such as P-PST assess various aspects of phonological processing, including phonological awareness, phonological working memory, and phonological retrieval.

Evaluation of phonological processing in cochlear implant users has been investigated in many studies in the literature (26-29). Although many cochlear implant users make significant progress in understanding oral language, this level of progress varies greatly between different users. Recent studies have demonstrated some problems faced by the CI users; e.g., the phonological abilities of school age children with cochlear implants are delayed compared to their peers (26, 29, 30). Thoutenhoofd compared the performance of cochlear implant users and children with normal hearing in schools in Scotland, and reported that the performance of cochlear implant users in writing, spelling, and math is weaker than that of their normal hearing peers. It is noteworthy that in cochlear implant users, with increasing age and exposure to school education, not only do academic differences decrease, but according to the literature, this gap gradually increases. This could have a direct impact on the academic lives of cochlear implant users (29). The common denominator of all six CI users in this study is the complaints of parents about children's educational disabilities, especially in spelling and writing. Although, in the present study, the ability to read and write after rehabilitation has not been quantified, Katz (2009) reported that phonemic training and phonemic synthesis programs can directly improve patients' reading and spelling abilities (3).

Katz, Masters, et al. (1998), explained the need for auditory processing rehabilitation in cochlear implant users and reported that the nature of the signal delivered by the cochlear implant to the brain is quite different from the signal of people who have normal hearing or have used hearing aids before cochlear implants (16). Katz (2009) states that the use of phonemic training significantly improves patients' performance in auditory processing capabilities in phonemic recognition test, phonemic synthesis test, and understanding everyday sentences (3).

The most common phoneme error patterns that occur in the current study include the omission and substitution patterns. In S3, S2, and S4, the number of omission errors is more common, and in S5, S1, and S6, the substitution errors are more common.

However, in S6, it should be noted that by entering phase B in the first few sessions of rehabilitation, we are faced with an increase in the number of phoneme errors, which leads to an increase in the number of omissions compared to substitutions. Therefore, it can be concluded that the most common pattern of phoneme error occurring in cochlear implant users participating in this study was the omission pattern. These findings are in line with previous studies (3). In the present study, the added phoneme error is in the third rank and its occurrence is far less than the omission and substitution. Phonemes play a vital role in different aspects of the buffalo model including evaluation, classifying the deficit, and planning rehabilitation, as well as monitoring the rehabilitation process and evaluating the effectiveness of the therapy program. Katz (2016) reports that by employing the PEA form, a therapy roadmap can be designed and it will solve many dilemmas. One of the most important benefits of PEA is in saving time and money for patients during a therapy program. If the frequency and pattern of phoneme errors are known before the therapy, rehabilitation programs can be designed to focus on the patient's main deficits, which will save time and money for the patient (19). In terms of effect size, all the indicators examined in all six CI users showed a positive response to rehabilitation. The most conclusive treatment effect occurred in S6, while it seems that among the studied samples, S6 showed the weakest performance in most indicators in the baseline phase. This finding is consistent with the findings of Katz (2009). Katz (2009) reported that treatment size is inversely related to the severity of problems. The more severe the auditory processing difficulties, the better the prognosis and the larger the expected effect sizes (3).

4-1. Study Limitation

Due to the effect of regular and consecutive rehabilitation sessions on the efficacy of the therapy program, providing proper travel conditions for parents and timely attendance at the sessions were among the problems of this study. This issue was solved as much as possible by providing a free travel service in the cochlear implant service. Also, observing the ceiling effect on some of the test findings led to the inadequacy of PND analysis in the study and replacing PAND analysis.

5- CONCLUSIONS

To conclude, the present study provides strong evidence demonstrating that Persian CI users are suffering from phoneme processing difficulties. This study also demonstrates that phoneme-based rehabilitation strategies improve the performance of deaf children with CIs. The findings revealed that despite extensive rehabilitation programs after cochlear implantation, the phoneme processing difficulties remained unsolved. We believe that these issues are due to the inadequate phoneme processing in the auditory cortex, especially in the mid-posterior temporal area. However, with introducing the phonemic interventions and relabeling phoneme engrams the performance of all six subjects in phonemic tests of auditory processing improved significantly based on C-statistics ($p < .00$). Also, the findings of effect size revealed a proper to decisive intervention based on PAND analysis. These findings suggest the importance and necessity of auditory processing rehabilitation procedures after cochlear implantation.

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