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Evaluation of Verbal Working Memory and Phonemic Analysis Skills in Adolescents with Cochlear Implant*

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Abstract

Introduction Adolescents with cochlear implants may have difficulty developing language and memory abilities.

Objective The primary objectives of this study are (1) to evaluate the language skills and verbal working memory performance of early and late diagnosed-intervened cochlear implanted adolescents and (2) to investigate the relationship between the verbal working memory and phonemic analysis skills in adolescents with cochlear implant.

Methods This study included 72 participants with cochlear implant aged between 10 and 18 years. The participants were divided into two groups; those who had first hearing aid at the age of 6 months at the latest and had a first cochlear implant in at least one ear at the latest at 24 months were included in the early group, all the others were in the late group. The phonemic analysis test, a subtest of the test of language development: Primary, 4th edition (TOLD: P-4) – Turkish version, was used to assess language-based abilities, and the meaningless word repetition (MWR) test was utilized to assess verbal working memory.

Results The adolescents with cochlear implants who received early diagnosis and intervention performed statistically significantly better in phonemic analysis scores and verbal working memory tests ($p < 0.001$). A statistically significant relationship was found between phonemic analysis and verbal working memory skills (Pearson, $r = 0.567$ and $r = 0.659$, $p < 0.001$).

Conclusions Rehabilitation of phonological skills can contribute to the development of verbal working memory in adolescents with cochlear implants. There is a need for further studies on this issue with more detailed tests.

Keywords
- working memory
- phonemic analysis
- cochlear implant
- adolescents

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Introduction

There are many variables such as duration of deafness, etiology, inner ear anomalies, family motivation, etc. that affect the language success in children with cochlear implants (CIs). One of the most significant of these factors is early diagnosis and intervention, and plasticity has become a critical role in both.[1,2] Some synaptic connections are generated with the continuity of the stimulus in the earliest years of life, whereas some other connections are lost due to the stimulus' ineffectiveness/deprivation.[3,4] The absence of long-term auditory input in the critical period is defined as deprivation.[5] After an increased period of hearing loss , the primary auditory cortex is activated by hearing the words with the CI, while some language areas are not activated.[6]

Even if optimal conditions are provided in factors such as implantation age, deafness duration, auditory rehabilitation, and so on, differences in speech, auditory perception, and cognitive skills can still be noticed in individuals with CIs.[7] There is a high correlation between verbal working memory and language processing.[8]

The working memory can be evaluated by different test batteries, such as digit span tests, meaningless word repetition, etc.[9,10] According to a few the studies conducted, the amount of verbal information in the phonological storage increases with age due to the increase in the internal repetition process.[11,12] Therefore, early diagnosis and intervention of children with CIs will enable them to reach language-based clues more easily and earlier, so the development of the verbal working memory will also be positively affected.

There have been numerous research papers investigating the relationship between verbal working memory and language skills. In a study conducted by Akçakaya et al., verbal working memory was reported to be correlated to speech perception, vocabulary, and implant usage time.[13] According to Davidson et al., the children with CIs experienced problems storing and processing linguistic information in working memory.[14] A pilot study by Kronenberger et al. reported that CI users compensated for the slow/ delayed language processing by using more verbal working memory cues.[15] In some other studies on this issue, they suggested that CI users could not benefit from their phonological and language strategies efficiently during their short-term memory and working memory-related tasks.[16–18] Another study revealed that verbal learning and memory skills were closely related to speech perception skills in children with CIs.[19] The relationship between phonological sensitivity and verbal working memory in children with CIs has already been extensively studied.[20,21] The phonological sensitivity has been demonstrated to have a considerable impact on verbal working memory,[22,23] and this relation is best understood using multicomponent models of working memory, such as those proposed by Baddeley.[24] This population has also been researched for nonword repetition.[25,26] Although recent research in teenagers has been limited, Edwards et al. revealed that auditory memory deficits remain during the adolescent period.[17] Despite the fact that there are numerous research studies on the subject, the goal of this paper is to underline the importance of working memory abilities in supporting the language development of CI users in adolescence, as well as to promote awareness among experts in the field.

The primary purpose of this study is to investigate whether there is a difference between adolescent CI users who had early and those who had late diagnosis-intervention in terms of verbal working memory and language skills. The secondary aim is to investigate whether there is a relationship between verbal working memory tasks, phonemic analysis skills, and language-based skills. Although there are numerous factors that affect the language and memory in cochlear implanted people, there are just a few studies in adolescents that use a homogeneous research sample. In addition to the literature, the current study focused on phonemic analysis skills and verbal working memory skills.

Material and Method

This study was approved by the ethics committee of the institution, under decision number 779. A signed informed consent form was received from the participants, and a detailed anamnesis on hearing loss was obtained.

Participants

This research involved 72 people who had a CI and were between the ages of 10 and 18. All participants have been using a CI for at least 1 year in at least 1 ear, and pure tone hearing thresholds with a CI are on average at most from 30 to 35 dB HL at frequencies of 500, 1,000, 2,000, and 4,000 Hz. The participants were divided into two groups: those who had early diagnosis and intervention and those who had late diagnosis and intervention.

The early group includes participants who were diagnosed with newborn hearing screening, started using a hearing aid at least at 6 months old, and started using a CI in one ear at least at 24 months old. The participants in the late group were those who were diagnosed with hearing loss at newborn hearing screening or later, and who started using their first hearing later than 6 months old, and who had their first CI in at least 1 ear after 2 years of age. The adolescents having an inner ear and/or auditory nerve abnormalities, pure tone hearing thresholds of more than 35 dB HL with a CI, using a CI in at most 1 ear for at most 1 year, with an additional disability, and not cooperating in tests were excluded from the study. All tests performed were evaluated with bilateral users only with the CI on the side of the experienced ear (with the first ear undergoing surgery being considered the experienced one), and for bimodal users only with the CI).

The demographic findings of the participants, such as age, gender, duration of deafness, age of CI use, and so on, were reported descriptively in the results section.

Evaluation Tools

All participants' hearing thresholds with CIs were detected in the free field after receiving the singed informed consent form and the comprehensive anamnesis. The three-syllable word test was used in the routine to determine the speech recognition threshold (SRT). The SRT is planned for older children and

Table 1 Speech recognition thresholds with cochlear implant

	Mean	Standard deviation	*p*
The early group	18.98	4.80	0.234
The late group	20.31	4.57	

people who are able to communicate. The results were compared to pure-tone test results to help identify hearing loss.

The phonemic analysis test, one of the subtests of the test of language development: Primary, 4th edition (TOLD: P-4) – Turkish version, was used to assess phonological abilities. The normative value should be 20 and above in this age range.[27,28] While correct answers are scored with 1, wrong answers are scored with 0. Finally, the total score is determined by adding the correct answer numbers together. These materials assess different aspects of working memory, given that digits are highly familiar and require little in the way of phonological analysis whereas nonwords require phonological analysis. The meaningless word repetition (MWR) list was used to examine the verbal working memory performance. The MWR list consists of 32 words and conducted a validity and reliability analysis in Turkish. The external A output of the GSI 61 audiometer (Grason-Stadler Inc., Eden Prairie, MN, USA) was connected to the computer with a cable to provide the recorded material from the MWR List, and the audio file was presented in the soundproof room at a rate of 60 dB SPL. The correct repetition of an average of 26 out of the 32 words is the expected value in this test in normal-hearing individuals of the same age as the study group.

Statistics

Statistical analyses were made using the IBM SPSS Statistics for Windows, Version 24.0 software (IBM Corp., Armonk, NY, USA). Whether the data were normally distributed or not was determined by histogram graphics and analytical methods (Shapiro-Wilk, Kolmogorov-Smirnov). The descriptive statistics were presented as mean and standard deviation since the data was normally distributed. Language-based scores and MWR scores between the early and late groups were analyzed with the independent samples t-test. The relationship between phonemic analysis and verbal working memory was examined by correlation tests (Pearson correlation). Statistical significance level was determined as %5.

Results

Firstly, the mean age in the group that received early diagnosis and intervention (n = 40, 26 of 40 participants were female) was 13.83 ± 1.97 years, while the mean age in the group that received late diagnosis and intervention (n = 32, 12 of 32 participants were female) was 14.94 ± 2.29 years.

All participants had neonatal hearing screening to determine the age at which they were diagnosed with hearing loss. The early group's mean age of first hearing aid use was 5.78 ± 0.48 months, whereas the late group's was 11.09 ± 1.99 months. The early group had a cochlear implantation onset age of 17.57 ± 2.82 months, while the late group had an onset age of 35.22 ± 7.83 months. Bilateral CIs were used in 20 people (9 people of them in late group), 15 people had bimodal CIs (8 people of them in the late group), and 37 people had unilateral CIs (25 people of them in the late group). To mention CI companies, 31 of all participants used devices from MED-EL (Innsbruck, Austria) and the remaining 41 of them used devices from Cochlear Ltd. (Sydney, Australia). The company names were provided as only descriptive information and were not included in any statistical analysis.

The mean hearing thresholds with CI at frequencies of 500, 1,000, 2,000, and 4,000 Hz were 17.30 ± 2.87 dB HL in the early group and 22.13 ± 3.42 dB HL in the late group.

When hearing loss etiologies and risk factors of the participants (n = 72) were examined, 11 participants had a history of high fever, 7 participants had hyperbilirubinemia, 16 participants had premature and low birth weight, and the remaining 38 participants had idiopathic hearing loss. In addition, 49 of 72 participants had consanguineous marriages.

The average score of SRT in the early group was 18.98 ± 4.80, while it was 20.31 ± 4.57 in the late group. Between the early and late groups, there was no statistically significant difference in SRT scores ($p = 0.234$). (►**Table 1**)

When the phonemic analysis test scores of language-based skills are analyzed, the mean number of correct answers in the early group was 18.20 ± 1.76, while it was 14.78 ± 1.56 in the late group. There was a statistically significant difference between the groups that had early and late diagnosis and intervention in terms of phonemic analysis skills ($p < 0.001$). (►**Table 2**)

The number of correctly repeated words in the MWR test applied to evaluate the verbal working memory was 24.93 ± 2.28 in the early group and 17.63 ± 2.81 in the late group. The number of phonemes repeated correctly was 43.88 ± 3.90 in the early group and 31.66 ± 4.33 in the late group. There was a statistically significant difference between the groups that received early and late diagnosis-intervention in terms of the correct number of words and the number of phonemes ($p < 0.001$). (►**Table 3**)

Regarding the secondary purpose of the study, when the relationship between phonemic analysis skills and meaningless word repeat performance and verbal study memory was examined, there was a moderate and positive correlation in

Table 2 The phonemic analysis scores of the groups

	Mean	Standard deviation	Maximum	Minimum	*p*
The early group	18.20	1.76	22.00	15.00	$p < 0.001$
The late group	14.78	1.56	18.00	12.00	

Table 3 The meaningless word repetition test scores of groups

	The number of correctly repeated words		The number of correctly repeated phonemes		
	Mean	Standard deviation	Mean	Standard deviation	*p*
The early group	24.93	2.28	43.88	3.90	$p < 0.001$
The late group	17.63	2.81	31.66	4.33	$p < 0.001$

the Pearson test between the correct number of repeated words and phonemic analysis score in the MWR test ($r = 0.567$, $p < 0.001$). There was a strong positive correlation in the Pearson test between the correct number of phonemes and phonemic analysis scores ($r = 0.659$, $p < 0.001$). These correlations were significant at the 0.01 level ($p < 0.001$).

Discussion

This study began with the goals of (1) affirming the importance of early detection and intervention for language development and related skills in adolescents with CIs, and (2) investigating the relationship between verbal working memory and language-based skills in adolescents with CIs. There was a considerable relationship between verbal working memory scores and phonemical analysis skills in prelingual deaf adolescents with CIs, which is unsurprising. The findings that adolescents with CI who had early diagnosis and intervention perform better was compatible with previous studies on this issue.[29–33] The reasons for the poor performance of adolescents with late diagnosis and intervention in this study could be explained by the duration of deafness. Until they have a hearing aid or a CI, children suffer from considerable auditory deprivation. As a result, these children may have difficulty with vocabulary, vocabulary description, learning, continuous learning, and auditory memory if they do not receive adequate and correct auditory input during the critical period for plasticity.[34] For example, there is a study reporting that the perception of phoneme improves with growth between the ages of 1 and 3, even better in those with early implants.[35] Many studies suggest that early-deafened and late-implanted teenagers benefit from a CI, contrary to the findings and hypothesis of the current study.[36,37]

Although there was a significant difference between the individuals who received early and late diagnosis and intervention in terms of language skills and verbal working memory performance, there was no significant difference between the two groups in the SRT scores. This result was thought to be due to the optimum levels of the CI thresholds and the SRT values obtained in accordance with this, since the CI adolescents who have been followed for many years have had thresholds close to the normal hearing range as a result of numerous fitting sessions. However, as in this study, it was observed that hearing thresholds at optimal levels were insufficient for successful language usage in daily life and memory skills. The language development and memory skills were investigated in a limited number of studies with cochlear implanted adolescents using language-based skills.[38–41] In these studies, similar to our current study, it was found that adolescents who were implanted early had better performance in verbal working memory skills.

The conclusion derived from these findings is that auditory memory is a critical factor in enhancing language abilities in adolescents with CIs. Because of the complex interactions between the sensory and cognitive processes that occur during the earliest years of life, failure to access sound and language deficiencies during this time reflect as academic and communication problems later in life.

This study revealed that there was a significant relationship between vocabulary and phonemic analysis skills, as well as non-meaningful word repeat performance in adolescents with CIs. During the MWR task, it indicated that adolescents with CIs are already applying their vocabulary knowledge. As a result, we expect that increasing the vocabulary knowledge of cochlear implanted adolescents and performing phonemic analysis will improve their verbal working memory skills.

The association between hearing loss, phonological skills, and verbal working memory has been studied intensively. This is also one of the few studies in adolescents with CIs that contain unique test materials. Attention was paid to ensure that characteristics such as deafness duration, cochlear implantation age, chronological age, and so on were homogeneous among the study participants. The limitation of this study is thought to be that the verbal working memory of the participating adolescents was evaluated with only one test battery. Future research may examine the relationships between grammar development, vocabulary, and verbal working memory with larger samples and more comprehensive tests.

Conclusion

The present study demonstrated that the long-term impact of early implantation on higher language skills is very significant. Also, the development of verbal working memory in adolescents with CIs can be supported by phonological skill rehabilitation.

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Conflict of Interests
The authors have no conflict of interests to declare.

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