

## RESEARCH ARTICLE

# Relationship between working memory capacity and speech perception in noise among children with cochlear implant

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## Abstract

**Background and Aim:** There is a controversy about cochlear implant usefulness for users since they do not develop speech and language with equal quality. Many researchers by controlling demographic and medical variables in this population suggested the contribution of neuro-cognitive factors such as working memory to this variation. The aim of this study was to compare working memory capacity between two groups of cochlear implantees who differ just in terms of speech in noise (SIN) scores.

**Methods:** In this study, 26 cochlear implanted children, aged 8-12 years who had received cochlear implant (CI) before age 3, took part and were divided into two groups of more than 75% and less than 60% based on their SIN scores. Both groups were matched for their medical and demographic characteristics, and underwent forward, backward digit span, and non-word repetition tests.

**Results:** There were significant differences in the scores of all three tests between the two groups ( $p < 0.001$ ). The scores of speech perception

in noise test were positively correlated with those of working memory tests.

**Conclusion:** The difference in working memory capacity between the two groups, and positive correlation between working memory capacity and SIN scores indicated the importance of working memory capacity in the ability of speech perception in noise in CI children. Thus, attention to working memory capacity in cochlear implant users seems important in planning for rehabilitation programs.

**Keywords:** Cochlear implant; children; speech in noise; working memory

## Introduction

Cochlear implant (CI) is a rehabilitative intervention for children and adults who suffer from severe to profound sensorineural hearing loss. Despite several advantages and benefits of CI for children affected by prelingual sensorineural hearing loss, especially in optimal listening environment, many of children with CI fail to achieve typical speech and language developmental milestones and show a wide variation in their ability of speech perception in the presence of background noise [1-3]. Several studies have been carried out to identify factors affecting such functional differences in these children by

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means of electrophysiological and behavioral tests, and reasons such as medical and demographic variables, and factors related to the prosthesis have been proposed [2,4-7]. Meanwhile some studies have suggested that these factors can only explain 37-64 percent of the differences in speech perception of children with CI and a large proportion of variances still remain unexplained [6]. Recent studies suggest that some of these differences may be due to underlying basic neurocognitive processes that are essential in speech and language development. Working memory is one of these neurocognitive processes that is critical for language development and speech perception [2,3,7].

Baddeley described these processes by introducing a multicomponent model of working memory. According to this model, working memory has four subcomponents: 1) a general central executive which has some top-down networks that correlate it to controlling attention and processing systems as a gate by regulating the flow of information, 2) the phonological loop that derives verbal phonological information from memory and stores them for a short time, 3) the visual-spatial sketchpad that tries to overlap phonological information with visual and spatial representation, and 4) an episodic buffer which extracts different coding from distinct memory resources and binds them to working memory data and makes a comprehensive description about the information that is temporarily stored in subcomponents of working memory [8].

The four-component model of working memory acts as a dynamic workbench. The general central executive component would allow relevant signals to enter the speech processing system, while simultaneously keeping out irrelevant signals for the function of speech perception. Then, general central executive component activates several words in the lexicon in long-term memory by means of episodic buffer. In this process, working memory acts as an interface between the input signal and lexicon in long-term memory, and retrieves the most proper mental lexicon that is most consistent with the input stimulus to be kept and other words be removed [1,2].

Working memory, which involves simultaneous processing and storage of information, has limited capacity, which varies across individuals. The extent of working memory involvement in speech perception varies depending on the difficulty of the listening conditions. The Ease of Language Understanding (ELU) model describes the role that working memory capacity plays in speech perception in challenging listening conditions. In optimal conditions, auditory input is intact and this gives better access to phonologically based long-term representations in the mental lexicon. Under such circumstances, processing of auditory input is automatic and implicit. When the input is weak or distorted, a mismatch may occur. In this situation, explicit processing is needed to match the suboptimal input with representations in the long-term memory store. Thus, efficient working memory function and good capacity may support the effectiveness of remedial explicit processing [9,10].

Since development and maturation of working memory depends on early auditory experience, it is expected that children with CI who are deprived from enough auditory input are at risk of delay and limitation of working memory maturation. Working memory function and capacity has been compared between normal hearing children and CI users by different tasks in many studies, demonstrating less working memory capacity in CI users compare to normal peers caused by auditory deprivation in early life [2,11].

In some studies, the correlation between speech perception and working memory span was evaluated, and the positive correlation and predictive potential of working memory test regarding speech and language development were established [2,5,11-14]. However, in these studies demographic or medical variables were not controlled. In recent studies on cochlear implantees, the differences in auditory evoked potentials in cochlear implant users with different levels of speech perception were assessed. They concluded that some of neurocognitive mechanisms were impaired and caused variations among cochlear implant users [7,15]. In this study, we aimed to assess working memory

capacity in two groups of cochlear implantees with relatively similar demographic and medical variables that all of them had high scores in speech perception in silence but differed in speech perception in noise. The outcome of this study could show the necessity of working memory evaluation and rehabilitation as early as possible in some cochlear implanted children to achieve better outcomes.

## Methods

Participants were selected by simple sampling method among students of special schools for the deaf students in Tehran. Based on inclusion criteria of the study, 26 cochlear implanted students aged 8-12 years (Mean=9.69, SD=1.63) with unilateral CI and without hearing aid on the other ear, participated in this study. The inclusion criteria were: prelingual-onset, bilateral severe to profound hearing loss, receiving CI before the age of 3, no history of neurological disorders, completion of the conventional rehabilitation course after receiving CI (auditory and speech language training) including the speech language therapy and educational setting encouraging development of spoken language and listening skills, a monolingual Persian home environment, and at least diploma degree for parents. Additionally, all the participants obtained a score of 80% or more in the speech perception in quiet test [by the first list of monaural selective auditory attention test (mSAAT) with eliminated competing message [16]. The research protocol was approved by the Ethics Committee of University of Social Welfare and Rehabilitation (Ethics code: IR.USWR.REC.1394.346).

Monaural selective auditory attention test (mSAAT) contains two lists of 25 monosyllabic words, presented in the presence of competing message (competing signal is a Persian story). Phrase "show me the..." was said before presenting every word. A 25-page booklet with six colored pictures in each page was prepared, and the child should choose the appropriate picture that is relevant to the heard word. Choosing target picture scored 1 and failing scored 0 [16]. For assessing the inclusion criteria, the first list

of mSAAT with eliminated competing message was used.

Monosyllabic words perception test contains twelve lists of 25 monosyllabic words (CV, CVC, and CVCC) [17]. In order to assess SIN ability, we selected one of the lists randomly and used it for all of participants. The words are presented via an audiometer and the child should repeat each word that heard.

Monosyllabic words perception in noise test and the second subtest of mSAAT were used to measure mean score of SIN. Monosyllabic word perception in noise test includes 25 words that are presented in the presence of speech noise at 0 dB signal to noise ratio via audiometer (Pejvak Ava, CA88). The students were divided into two groups according to the mean scores obtained in previous tests. Those students whose score was more than 75% in both SIN tests were labeled as the first group and those students whose score was less than 60% in both SIN tests were labeled as the second group. The students whose score was in the range of 60-75% were excluded from the study, because of the possibility of distorting the results of the study.

Working memory of participants was assessed using forward, backward digit span [18], and Persian version of non-word repetition tests [19]. Forward and backward digit span were presented by live voice at a rate of approximately one digit per second without the help of any instrument while the child was able to look at the examiner's face. Digit sequences were presented beginning with a length of two digits, and two trials presented at each increasing list length. Testing ceased when the subject failed to accurately report either trial at one sequence length, or when the maximal list length was reached (9 digits forward, 8 backward). All students were given instructions that they should repeat what they remember of the series of numbers they heard. Maximum sequence which was repeated twice correctly was considered as their score. In non-word repetition test, the students were instructed that they would hear a term with no meaning. They were asked to repeat it as correctly as possible. After a trial period, the target non-words were presented.

**Table 1. Mean (standard deveiation) speech in noise and working memory scores in cochlear implanted students**

Test	Mean (SD)	
	First group (n=13)	Second Group (n=13)
mSAAT (%)	80.92 (5.45)	37.23 (12.15)
mWIN (%)	84.00 (6.32)	44.92 (10.6)
FDS (n)	4.23 (0.59)	2.92 (0.95)
BDS (n)	3.31 (0.63)	0.38 (0.96)
NWR (n)	27.69 (4.17)	17.53 (5.18)

n; number, mSAAT; monaural selected auditory attention test, mWIN; monosyllabic word perception in noise, FDS; forward digit span, BDS; backward digit span, NWR; non-word repetition

Producing the target non-word scored 1 and failing scored 0 [20].

Results were analyzed using SPSS 20, normal distribution of data was confirmed by Shapiro-Wilk test. Independent t-test and Mann-Whitney U test were used to compare SIN scores and working memory test results between two groups. Pearson and Spearman coefficients were

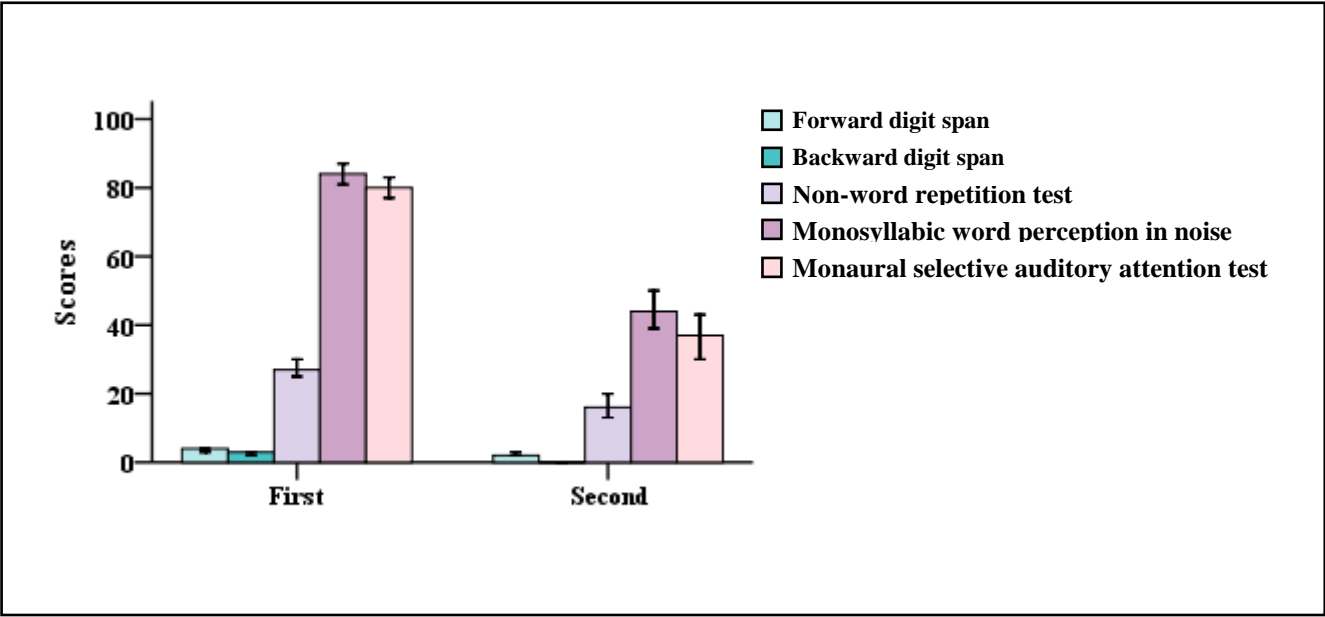
used to detect the relationship between working memory function and speech in noise (SIN) scores. For all analyses,  $p<0.05$  was considered as statistical significance. This study had 80% power and 0.5 test error.

**Results**

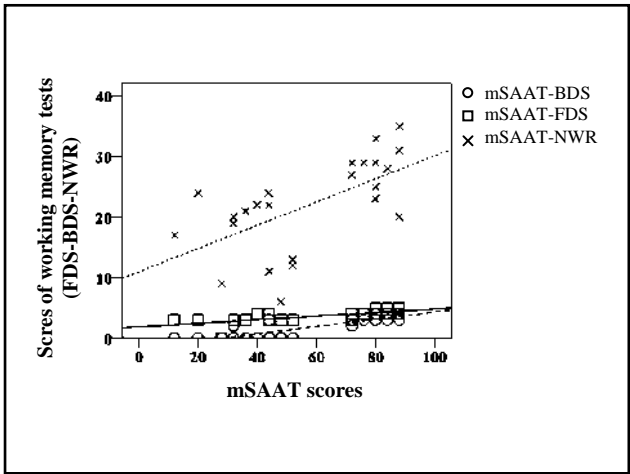
Participants were divided into two groups according to their mean score of SIN tests. Descriptive data of these two groups are presented in Table 1 and Fig. 1.

Mann-Whitney U test revealed significant difference between two groups in forward digit span ( $p<0.001$ ) and backward digit span ( $p<0.001$ ). Leven test was used to check the homogeneity of variances of scores of two groups in non-word repetition test. Since variances of non-word repetition scores were equal in two groups ( $p=0.07$ ), we used independent t-test to demonstrate the differences between two groups, that showed a significant difference in non-word repetition ( $p<0.001$ ).

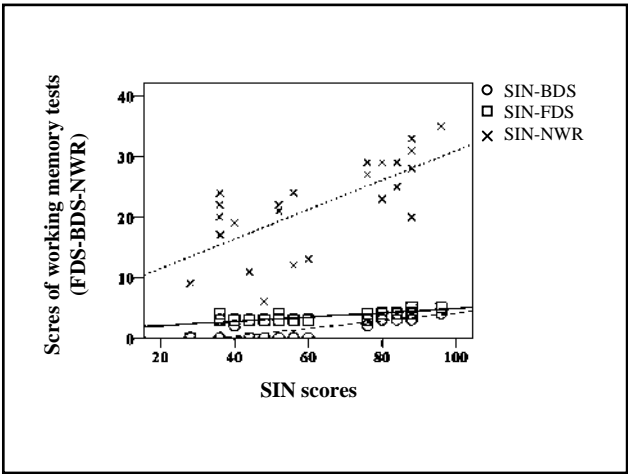
The results of correlation analysis by Spearman and Pearson tests showed the scores of SIN tests were positively correlated with all working memory tasks (Figures 2 and 3). The results also showed that mSAAT and monosyllabic word



**Fig.1. Mean (±2SEM) of the tests scores in the first and second groups.**



**Fig. 2. Relationship and correlation between mSAAT and working memory tests. BDS; backward digit span, FDS; forward digit span, mSAAT; monaural selective auditory attention test.**



**Fig. 3. Relationship and correlation between SIN test and working memory tests. SIN; monosyllabic word perception in noise, FDS; forward digit span, BDS; backward digit span, NWR; non-word repetition test.**

perception in noise scores were positively correlated with all tasks of working memory ( $p<0.001$ ) (Table 2).

**Discussion**

One of the findings of this study was the significant difference between two groups in terms of working memory capacity. In line with many previous studies, the current study showed that mean scores of working memory tests were lower in both groups of cochlear implantees

than their normal counterparts. Soleymani et al. found that there was a significant difference in forward, backward digit span, and non-word repetition scores between CI and normal hearing groups [11]. Geers et al. compared backward and forward digit span between cochlear implant users and their normal counterparts [21]. They suggested that early auditory deprivation in life affected encoding and retaining phonological data, because hearing has a pivotal role in development of phonological encoding skills. However, the findings of this study showed that despite the high score of both groups' members in speech perception in silence, there is a wide variation in their working memory performance, and this variation is not predictable only by scores of speech perception in silence. Another finding of this study was the significant positive correlation between working memory capacity and SIN score. Harris et al. in their longitudinal study also revealed that the scores of forward and backward digit span tests had a significant positive correlation with scores of speech in noise (0.42 and 0.40, respectively) [2]. Kronenberger et al. according to significant positive correlation between forward and backward digit span with speech and language skills

**Table 2. Correlation between forward, backward digit span and non-word repetition tests with mSAAT and mWIN**

Working memory test	mSAAT		mWIN	
	r	p	r	p
FDS	0.80	<0.001*	0.80	<0.001*
BDS	0.82	<0.001*	0.80	<0.001*
NWR	0.64	<0.001**	0.71	<0.001**

mSAAT; monaural selective auditory attention test, mWIN; monosyllabic word perception in noise, FDS; forward digit span, BDS; backward digit span, NWR; non-word repetition  
\*Spearman, \*\*Pearson

such as speech perception in noise, concluded that working memory related to growth of speech perception ability [13]. They claimed that working memory abilities in early childhood strongly predicted a wide variety of speech and language skills –including spoken-word recognition, sentence repetition, vocabulary, and reading [2,13].

There is interdependence between sensory experience and working memory development, so conditions such as hearing impairment or using cochlear implant that affect or alter sensory input may have secondary and unpredictable effects on working memory functions [1,2,22]. Thus, it becomes clear that disorders in working memory capacity and performance may interfere with speech perception in noise among children with cochlear implants.

There are many factors that affect SIN, but because of impossibility in evaluating all of them simultaneously, we just focused on working memory. Some limitations such as lack of standardized test for cochlear implanted children did not permit us to study accurately working memory and SIN ability, because in most of these tests the child had to answer verbally, so their articulatory problems make the evaluation difficult. Also, equipments and time constraints were another limitation. Because of some administrative limits, we could not employ stricter inclusion criteria such as just a specific type of cochlear implant device, unilateral or bilateral users, and hybrid or bimodal amplification. Lack of cooperation from the managers of schools to provide records of students and parents of cochlear implantees was another limitation.

## Conclusion

Differences in speech-language outcomes in children with CIs are not fully explained by conventional criteria including device type, demographic, and medical factors. Some part of this unexplained variance in speech-language outcomes may be a result of differences in core underlying neurocognitive functions that provide the foundation for the development of speech and language skills, specially working memory. Our findings were a sign of limited working

memory capacity in the second group whose SIN scores were lower than the first group despite similarity of scores on speech perception in silence. In the other words, the effects of sensory deprivation on working memory development are not similar in all of the cochlear implantees and some inherent differences in working memory development that are unclear may underlie these variability. It showed that paying attention to usual criteria is not efficient to predict speech and language outcomes in cochlear implanted children, and it is necessary to focus on working memory evaluation and rehabilitation more than ever.

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