REVIEW ARTICLE

Computerized cognitive training for improving cochlear-implanted children's working memory and language skills

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Abstract

Sensory deprivation, including hearing loss, can affect different aspects of a person's life. Studies on children with hearing impairment have shown that such patients, especially those with cochlear implants (CIs), suffer from cognitive impairments, such as working memory problems and poor language skills. The present study aimed to examine the efficacy of cognitive computer training in improving working memory and language skills in children with a CI.

This research was a quasi-experimental study with a pre-test-post-test design and a control group. Fifty-one children with a CI aged 6-12 years were recruited through convenience sampling and randomly assigned to the control and treatment groups. The Wechsler Working Memory Subtest and the Test of Language Development (TOLD) were used to evaluate children's working memory and language skills pre- and post-treatment. The treatment group attended twenty 50-60-minute cognitive computer training sessions three times a week. Sina-Working Memory Training was used to provide the treatment group with working memory training, whereas no intervention was provided to the control group. Univariate and multivariate analyses of covariance were used to analyze data.

The results demonstrated the efficacy of cognitive computer training in improving the performance of cochlear-implanted children's working memory (auditory and visual-spatial) ($P < 0.01$). The results also pointed to improved performance in sentence imitation ($P < 0.01$), word discrimination ($P < 0.01$), and phonemic analysis subtests ($P < 0.01$).

Overall, the findings indicated that cognitive computer training might improve working memory and language skills for children with CI. Therefore, the development and execution of such programs for children with CIs seem to improve their cognitive functions, such as working memory and language skills.

Keywords: Working memory; Cochlear implant; Language Development; Cognitive training; Children

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Introduction

Studies show that early hearing loss can negatively impact the speech, language, and neurological development of children with cochlear implants (CIs) (1,2). Children with CIs exhibit deficiencies in their working memory as a cognitive element of empowerment that can be accounted for by early delay in hearing (3,4). Several studies have demonstrated reduced language and cognitive skills in children with CIs (3-5). Given that auditory experiences can be served as the basis for the development of cognitive abilities, conditions, such as hearing impairment, can be associated with substandard performance in various cognitive tasks (3,6) and language disorders (7) by interfering with auditory inputs. These children may face greater difficulties in a number of cognitive functions, such as working memory, planning, inhibition, and shifting, compared to children with typical levels of hearing (8-10). Acknowledging the negative impacts of early hearing impairment on neuropsychological functions and communication ability, numerous studies argue that deficient auditory input reception induces neuropsychological function defects. Given the close relationship between neuropsychological functions, working memory in particular, and language and speech skills (11), such defects can be a significant factor in causing language and speech disorders in children with CIs. Therefore, the neuropsychological functions of children with CIs have become an area of interest for researchers. As a neuropsychological function, working memory contributes significantly to cognitive information processing and is defined as a mental workspace involved in controlling, regulating, and active processing of information to accomplish cognitive tasks (12,13). Working memory refers to the ability to store, decrypt, and manipulate information while simultaneously performing another cognitive activity (13). It is considered a comprehensive system linking subsystems to short- and long-term memory performances (13,14). Baddeley divided working memory into four components: (1) central executive, (2) phonological loop, (3), visuospatial sketchpad, and (4) episodic buffer (13).

Some studies have demonstrated a relationship between working memory and speech and language skill development (15,16,17,18, 19), while others have investigated the role of memory in verbal communication and speech skills of children with CIs (19). The results point to a relationship between working memory and language skills, such as speech perception (17,20) and reading comprehension (21,22), suggesting that some memory components can be regarded as the common foundation of skills, such as speech production and perception or even language and reading comprehension (19). There is a close relationship between memory span and word recognition (23), and children with CIs with broader memory spans perform better in spoken word recognition tasks (1,11,19,23). Therefore, research evidence indicates the significance and necessity of working memory development for language and speech development (10), as well as for predicting performance in numerous cognitive activities, such as speech perception (15,24) and language and speech skills (10,23). Given the susceptibility of children with CIs to impairments, such as working memory deficits, evidence concerning the relationship between working memory and speech and language development (10,15,18) and the reduced working memory of children with CIs (2), improving working memory may contribute to the enhancement of language skills in these children.

The flexibility and improvability of cognitive functions, such as working memory, have been reported (25,26). Numerous programs have been designed to improve cognitive skills, including working memory. Computer-based cognitive programs are among the most popular and widely used programs, which have been used in several studies to improve cognitive functions in various groups of children, including those with attention-deficit/hyperactivity disorder (ADHD) (27), deficient working memory (28), attention deficit disorder (ADD), and special needs (29). In addition, Kronenberger et al. examined the efficacy of working memory training programs in improving working memory and language skills in a small group of children with CIs aged 7-15 years (1). They reported improved working memories in the post-test and follow-up as well as enhanced language skills.

Despite the multiplicity of research on the efficacy of cognitive computer training in improving working memory in various groups of children, including children with special needs (30), ADHD (27), and emotional and behavioral difficulties (31), the number of studies on the efficacy of such programs in improving working memory and particularly language and speech skills in children with CIs is limited (1). Given the originality of using computerized cognitive training to improve various cognitive domains, particularly in children with CIs, the reduced working memory of such children, and the close relationship between cognitive skills (including memory) and speech and language skills, examining the efficacy of such training in improving working memory and language skills of children with CIs appears to be necessary. Accordingly, this study aimed to investigate the effectiveness of computer-based cognitive training (CCT) on visual and verbal working memory and language skills of children with CIs aged 6-12 years.

Materials & Methods

This was a quasi-experimental study with a pre-test-post-test control group design. The statistical population consisted of all children aged 6-12 years undergoing CI surgery in Baqiyatallah Hospital, Tehran. The participants were selected among those who had undergone this surgery at least five years ago and were living in Tehran. Based on the convenience sampling method, the author visited the Cochlear Implant Center of Baqiyatallah Hospital to prepare a list of children who met the inclusion criteria and contact their families. After five sessions at different intervals, 60 families briefed on the research conditions announced their readiness to participate in the study. The participants took the working memory test and the language development test (TOLD) and were randomly assigned to the control and treatment groups, each comprising 30 subjects. The treatment group was trained based on an intervention program, and those in the control group were placed on the waiting list. Because some children did not continue the intervention program, the treatment and control groups were reduced to 27 and 24 individuals, respectively.

2.1 Inclusion and exclusion criteria

Inclusion criteria

The age of 6-12 years

Undergoing a CI surgery at least five years ago

Undergoing a CI surgery in Baqiyatallah Hospital, Tehran

Exclusion criteria

Affliction with any physical illness or mental disability

Studying in exceptional children's schools (low average IQ)

The mean age of the children participating in the study was three years and six months at the time of surgery. All children were native Persian speakers and participated in the 100-session speech therapy program after surgery. Speech therapy programs were provided free of charge by speech therapists at Baqiyatallah Hospital after surgery to all children undergoing cochlear implantation.

The descriptive and demographic data of treatment and control groups are separately displayed in Table 1.

As can be seen in Table 1, the control and treatment groups consisted of 24 and 27 students, respectively. The mean age in the treatment and control groups was 9.48 and 9.95 years, with standard deviations of 1.80 and 1.36, respectively. The mean age of all children was 9.70 years, with a standard deviation of 1.61. Out of the 51 participants, 26 (50.98%) and 25 (49.02%) were male and female, respectively. The mean age of male and female students was 9.88 and 9.52 years, respectively.

Sina-Working Memory Training was used to provide the treatment group with working memory training for twenty 50-60-minute sessions, three times a week. The Persian version of the test of language development (TOLD) was used to evaluate children's language skills (32,33). In addition, the Wechsler Working Memory Subtests were used in pre-test and post-test to assess children's working memory (34).

3. Measures

3.1. The Wechsler working memory scale

The Wechsler Intelligent Scale for Children (Fourth edition) Digit Span (working memory) subscale was used to evaluate the auditory working memory of children with CIs (34). The Persian version of this scale was adapted to Iranian culture (35). Subscale raw scores for digits forwards and digits backward were administered.

3.2. Test of language development

The Persian version of the TOLD was used to examine of language skills of children with CIs (32,33). As one of the most valid tests for language development assessment, the TOLD was translated and standardized by the Iranian Special Education Organization in 2002 (32,33). Given the study objectives, sentence imitation, word discrimination, and phonemic analysis subtests were administered.

3.2.1. Sentence imitation

This subtest measures a child's ability to imitate sentences spoken by an examiner. The sentence is spoken intelligibly in exactly the same manner as written in the test book, and the child is required to repeat the exact same sentence.

3.2.2. Word discrimination

This subtest measures a child's ability to recognize the differences in speech sounds. An examiner says two words, and the child has to decide whether they are the same.

3.2.3. Phonemic analysis

In this subtest, an examiner says a word to the child and asks him/her to repeat it without one of its phonemic units (32,33).

3.3. Intervention program

3.3.1. Sina-working memory training

Sina-working memory training software was developed by Sina's Cognitive-Behavioral Sciences Research, Tehran, Iran. This software is a collection of computer games developed to improve working memory via computer training tasks. The tasks are diverse and can be performed by children aged six years or more. These tasks provide children with structured opportunities for training and include tasks requiring to verbal, visual, forward, and backward memory. Tasks are of various difficulty levels. Given the research objectives, tasks requiring working memory training were used in twenty 50-60-minute sessions.

3.3.2. Software environment

This software has a graphical background image of the sky and a meadow. After logging on to the application and defining a user, the main menu is accessible. It shows different working memory assignments, including auditory working memory and visual working memory activities. Every assignment has different levels graded according to difficulty. Based on the research goals, auditory working memory assignments were used as working memory computer activities in this study.

3.3.3. Auditory memory activities

By selecting Auditory Memory, two options appear on the screen: forward auditory memory and reverse auditory memory. Every option includes numbers, letters, and pictures.

After selecting numbers, letters, or pictures from auditory memory, a new page appears with nine yellow orbs. On the top of the screen, users can select a difficulty level ranging from one to nine. In other words, level one requires a subject to listen to one item and then remember it. At the most difficult level (Level nine), a subject is asked to remember nine items, which were played previously. The screen also shows the elapsed time and score on the right and left sides, respectively. If a child gives a correct answer in every attempt, 20 points will be received. However, ten points are subtracted for every wrong answer. If a child can give five correct answers at a level, the next level of difficulty will be activated.

3.3.4. Numerical auditory memory activities

In numerical auditory memory activities, numbers appear on nine yellow orbs (3*3) on the screen. Then, the subject is asked to remember and select the numbers, to which he listened previously.

3.3.5. Alphabetical auditory memory activities

In alphabetical auditory memory activities, letters appear randomly on nine yellow orbs presented to a subject who is asked to remember the letters they previously listened to.

3.3.6. Picture auditory memory activities

After the application distributes the names of different pictures, the pictures are shown as yellow orbs to a subject who is asked to remember and select the pictures correctly.

A subject is rewarded with scores and audio feedback for every correct answer.

3.3.7. Assigning activities to participants

In the auditory memory activities in every section (numbers, letters, or pictures), a ring is played for a child after a therapist clicks on Start. Then, a picture name, number, or letter is played by the application. After a short pause, the ring is replayed, and pictures, letters, or numbers appear on the screen. Now the child is asked to remember letters, numbers, or pictures played by the application and click on each of them in order of presentation. If the child can remember the presented audio stimuli correctly, he/she will receive 20 points.

All steps are executed in reverse auditory memory activities (numbers, letters, and pictures) in the same order. However, the child is asked to remember the presented auditory information and stimuli from the end to the beginning.

3.4 Ethical considerations

Informed consent was obtained from the parents and the study was approved by the Ethical Committee of Baqiyatallah University of Medical Sciences.

Results

Descriptive data obtained from the Wechsler Working Memory Subtest is presented in Table 2.

The mean, standard deviation, standard error of the mean, and minimum and maximum working memory test scores divided by subscales, as well as the total scores of the control and treatment groups, are displayed in Table 2. The mean working memory subscale scores and also the total score increased following the intervention in the treatment group. However, no significant change was seen in the control group scores in the pre-test and post-test. Analysis of covariance (ANCOVA) was used to determine the significance of differences in the pre-test and post-test scores.

According to Table 3, the total working memory score of the treatment group increased significantly compared to the control group following the intervention ($\eta P2 = 0.55$, $P= 0.001$, $F= 59.49$, and $df = 1$). The test’s statistical power arrived at 1.00, indicating its high power.

Multivariate analysis of covariance (MANCOVA) was used to examine the efficacy of the intervention program in the working memory of children with CIs in terms of the working memory subscales.

The intergroup test results suggested a significant difference in the treatment group scores in both subscales following the intervention ($P \leq 0.01$) (Table 4). In other words, a statistically significant difference was found in both working memory subscales after adjustment for the pre-test effect. This indicates that the treatment group performed better compared to the control group in terms of the two working memory subscales after participating in the intervention program.

Language and speech skills

Table 5 shows a significant increase in the TOLD subscale mean scores (sentence imitation: 16.55 and 19.14, word discrimination: 14.96 and 16.51, and phonemic analysis: 8.40 and 10.55) in the pre-test and post-test. MANCOVA was used to determine the significance of differences in pre-test and post-test scores.

The findings suggested that the intervention program administered to the treatment group for sentence imitation ($P = 0.001$, $F = 42.26$), word discrimination ($P = 0.001$, $F = 17.08$), and phonemic analysis ($P = 0.001$, $F = 15.46$) was statistically significant at 0.01. In addition, a statistically significant difference was observed in the treatment group scores following the intervention (Table 6).

All ANCOVA and MANCOVA assumptions (Homogeneity of variances, regression homogeneity, and data normality) were analyzed and confirmed before conducting statistical analyses.

Table 1. Descriptive data of treatment and control groups based on age and gender

Feature	Group	Number	Mean (age)	SD	SE	Min	Max
Age	Treatment	27	9.48	1.80	0.34	6	12
	Control	24	9.95	1.36	0.27	7	12
	Total	51	9.70	1.61	0.22	6	12
Gender	Male	26	9.88	1.42	0.27	7	12
	Female	25	9.52	1.80	0.63	6	12
	Total	51	9.70	1.61	0.22	6	12

Table 2. Descriptive data obtained from the Wechsler Working Memory Subtest reported for each subscale

Subscale	Group	Stage	Mean	SD	SE	Min	Max
Forward recall	**Treatment**	**Pre-test**	7.85	1.26	0.24	5	10
		Post-test	9.81	1.17	0.22	7	12
	Control	**Pre-test**	7.91	1.44	0.29	5	11
		Post-test	8.04	1.19	0.24	6	10
Backward recall	**Treatment**	**Pre-test**	5.55	1.28	0.24	3	9
		Post-test	7.11	1.18	0.22	5	10
	Control	**Pre-test**	5.29	1.04	0.21	3	7
		Post-test	5.70	1.19	0.24	4	8
Total score	**Treatment**	**Pre-test**	13.40	1.88	0.36	8	17
		Post-test	16.92	1.75	0.33	13	21
	Control	**Pre-test**	13.20	1.99	0.40	8	18
		Post-test	13.75	1.89	0.38	10	18

Table 3. Univariate ANCOVA results of the working memory test

Source	SS	df	F	p	Partial Eta squared	Observed power
Pre-test	66.86	1	33.61	0.001	0.41	1.00
Group	118.34	1	59.49	0.001	0.55	1.00
Error	95.48	48	-	-	-	-

Table 4. Intergroup MANCOVA results after adjustment for the pre-test effect divided by the working memory subscales

Source	SS	df	F	p	Partial Eta squared	Observed power
Direct recall	41.36	1	50.76	0.001	0.51	1.00
Backward recall	18.53	1	23.12	0.001	0.33	0.99

Table 5. Descriptive data from TOLD subscales

Subscale	Group	Stage	Mean	SD	SE	Min	Max
Sentence imitation	**Treatment**	**Pre-test**	16.55	2.20	0.42	12	21
		Post-test	19.14	2.16	0.41	15	23
	Control	**Pre-test**	14.95	2.29	0.46	11	18
		Post-test	15.37	2.20	0.44	11	19
Word discrimination	**Treatment**	**Pre-test**	14.96	1.55	0.29	11	18
		Post-test	16.51	1.08	0.20	14	19
	Control	**Pre-test**	14.58	1.61	0.32	11	18
		Post-test	14.91	1.99	0.40	11	19
Phonemic analysis	**Treatment**	**Pre-test**	8.40	2.08	0.40	4	12
		Post-test	10.55	2.18	0.42	6	15
	Control	**Pre-test**	8.66	1.92	0.39	5	13
		Post-test	9.04	1.65	0.33	6	13

able 6. Intergroup MANCOVA Results after Adjustment for the Pre-test Effect Reported for Each ubscale

Source	SS	df	F	p	Partial Eta squared	Observed power
Sentence imitation	53.54	1	42.26	0.001	0.51	1.00
Word discrimination	13.81	1	17.08	0.001	0.29	0.98
Phonemic analysis	16.80	1	15.46	0.001	0.27	0.97

Discussion

The results indicated the efficacy of cognitive computer training in improving the working memory and language skills of children with CIs, indicating that cognitive computer training significantly improved working memory and language skills ($p \leq 0.01$).

The results of this study, therefore, are consistent with those of other studies regarding the efficacy of cognitive computer training in improving working memory (1, 27-28, 30, 36-40). This points to the efficacy of cognitive computer training in improving working memory in various groups of children, including normally developing children, children with learning disabilities, children with ADHD, and children with CIs. Dahlin demonstrated the efficacy of such training in improving the memory, attention, and concentration of children with ADHD (30). Alloway et al. examined the efficacy of working memory cognitive computer training in elementary students (36). They demonstrated the efficacy of such training in improving verbal and visual-spatial working memory performance not only immediately after the conclusion of the intervention program but also eight months after the research (36,41), which indicates sustained improved performance. Kronenberger et al. assessed the efficacy of cognitive computer training in improving working memory in a small group of children with CIs (1). A significant improvement was seen in their working memory performance after the intervention and in the follow-up, which is consistent with the results of the present study.

In addition to a direct impact on cognitive skills, including memory, such training can influence other cognitive functions in children. Roughan and Hadwin, for instance, reported improved academic and behavioral inhibition performance as well as diminished emotional-behavioral, educational, and even mental health issues (31). In addition to significant improvement in the visual-spatial working memory of children with ADHD, as the primary variable, following the intervention, Klingberg et al. reported significant improvement in secondary variables, such as verbal working memory, response inhibition, and reasoning (27). In particular, cognitive computer and working memory training can influence other dimensions of cognition and memory.

In addition to working memory performance, the effect of cognitive computer training on improving the language skills of children with CIs was examined. Results from the sentence imitation, word discrimination, and phonemic analysis subtests indicated enhanced performance in the specified language skills in children with CIs. Accordingly, it can be concluded that cognitive computer training can be served as an effective intervention in improving language skills in addition to cognitive abilities, such as memory. This is in line with the findings of Kronenberger et al. and Ingvalson et al., pointing to the efficacy of cognitive computer training in enhancing language skills (1, 4).

The results of Abbasian Nik concerning the efficacy of working memory training in improving language skills of children with CIs are consistent with those of the current study (42). In this regard, regarding language skills as a secondary dependent variable, Kronenberger et al. reported that cognitive computer training could improve working memory in children with CIs and enhance language skills (1). In addition to evaluating working memory, they used a sentence repetition subtest to assess language skills. Sentence repetition is a difficult task for children with CIs and is strongly correlated with their speech comprehension performance (11). In other words, sentence repetition appears to be one of the best examples of core spoken language skills. As one of the most effective clinical indicators of specific language impairments (SLIs) (43-45), sentence repetition is also associated with the working memory of children with CIs (1,43) and comprises such components as working memory and speech and linguistic perception. Therefore, improved sentence repetition performance can be indicative of enhanced language skills in this group of children. In addition to the evidence from the sentence imitation subtest, as the main component of language development, two other subtests, namely the word discrimination and phonemic analysis subtests, were also administered to examine language skills. These two subsets appear to be related to memory capacity. The results demonstrated improved performance in all three skills. Given the relationship between language skills and working memory in children with CIs, it can be concluded that working memory computer training can improve their working memory and, subsequently, language skill performances.

The current study did not follow children up after the program. Future work should also examine the impact of this intervention on school achievement more broadly.

Considering the novelty of this area of research, it seems that more evidence is needed to prove the effectiveness of CCT in the improvement of language skills of children with CIs. In other words, although many studies have investigated the effectiveness of computer-based cognitive rehabilitation interventions on the cognitive skills of different groups of children, a few studies have dealt with the effectiveness of such interventions on children with CIs. Moreover, studying the indirect effects of computer-based cognitive interventions on the language skills of children with CIs is another intriguing area of research in this field that has been less considered. One example of the limited studies conducted on language skills in this area is the pilot studies carried out by Kronenberger et al., whose findings are consistent with the results of this study regarding both the direct and indirect positive effects of computer-based cognitive interventions on working memory and language skills of children with CIs, respectively. Emphasizing the novelty of applying computer-based cognitive interventions for children with CIs, Kronenberger et al. stated that more similar studies with follow-up periods are needed to be conducted on larger samples using various measurement tools to confirm the positive effects of such interventions on children with CIs.

In conclusion, given the obtained findings regarding the reduced memory of deaf and hearing impaired children and children with CIs as well as the findings of other studies on the efficacy of cognitive computer training in improving working memory, CI user's working memory and language skill performances can be enhanced by the design, development, and implementation of such programs. Considering the strong relationship between cognitive and academic-social skills, enhancing the cognitive abilities of children can help them achieve numerous positive academic and social outcomes. Parents and specialists can use the simplicity of educational software and children's interest in performing computer-based tasks, deriving from their passion for computer games, as opportunities to improve children's performance in various areas, particularly their cognitive functions, which form the foundation of numerous children's abilities. Given that the efficacy of the specified interventions was reported to be greater at earlier ages, it is recommended that these programs be offered to children with CIs early.

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Author's Contribution

Ali Sharify: substantial contribution to the conception and drafting the work, Acquisition, analysis of data and interpretation of data for work, perform of tests and psychological assessments. Mohammad Ajalloueyan,Participant's selection, ENT consultation and Cochlear implant surgery. Masoumeh Saeedi,Participant's selection, ENT consultation and Cochlear implant surgery. Susan Amirsalari,Clinical diagnosis, participant's selection, analysis and interpretation of psychological tests and follow up.

Conflict of Interest

There was no conflict of interest stated by the authors.

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