Working memory training and language outcomes in children with cochlear implants

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Objective
The aim of this study is to provide information on whether improvements in language skills might be achieved by improving working memory capacity in cochlear-implanted children.

Patients and methods
This study was carried out on 30 prelingual cochlear-implanted children at the Hearing and Speech Institute. They were divided into two groups: group I received communicative therapy plus a working memory training program. Group II received communicative therapy only. Post-therapy evaluation was carried out after 6 months using the Modified Preschool Language Scale-4 for assessing language and the working memory subtests measures of the Stanford–Binet Intelligence Scale '5th Arabic version' for the assessment of working memory.

Results
The results of this study showed an improvement in verbal working memory capacity, nonverbal working memory capacity, and the total working memory in the group of children with cochlear implants (CIs) who received 6 months of a working memory training program in addition to communicative therapy. The findings indicate that there is an improvement in the verbal and nonverbal working memory in the participants following the training on certain tasks in the computer-based working memory training program. This will lead to an improvement in the language skills as well.

Conclusion
Working memory training may improve some memory and language skills for children with CIs. As a result, interventions specifically designed to address the basic underlying verbal working memory deficits of children with CIs may be expected to have wide-ranging effects that generalize well beyond the trained working memory tasks and stimuli themselves and show transfer to nontrained language perception and memory tasks.

Keywords:
cochlear implants, language development, working memory

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Introduction

Working memory is very important in every one's life, especially in communication skills. It maintains and manipulates information in the mind for a brief period of time [1]. It is also vital for storing short-term information, words, and meanings [2].

Auditory deprivation is the absence of auditory stimulation as a consequence of profound bilateral hearing loss. Auditory deprivation before cochlear implantation can lead to auditory processing deficiency in particular, a deficiency in auditory sequential short-term memory [3].

The brain is an integrated system in which no part acts alone; it is shaped by experience. A period of poor or no access to sound may affect the neural organization and plasticity of brain systems, such as working memory, processing, executive control, attention, and learning. All these processes are required to perceive and use language efficiently [1].

Cochlear implants (CIs) restore some components of hearing to children with profound hearing loss, resulting in the development of speech and language skills in many cases. However, an early period of hearing loss, followed by limitations in auditory input from CIs, has an ongoing impact on speech-language and other neurocognitive development in many children with CIs. As a result, large individual differences in speech perception, speech production, and language outcomes are encountered in the CI population despite their similarity in most

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preoperative criteria and postoperative management [4]. 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.

Neurocognitive functions, ranging from basic sensory processes to higher-order thinking, are highly integrated and interdependent for their development throughout the lifespan [5]. For example, sensory experiences such as sound and auditory input provide building blocks not only for speech and language but also for cognitive functions such as sequencing abilities and memory skills [6]. Working memory skills have been found to correlate with the development of speech-language abilities in children with CIs.

Working memory, however, also plays an important role in cognitive functioning in children with CI. There are many types of working memory (general, visuospatial, and phonological working memory) [7]. Dawson *et al.* [3] found spatial working memory capacity to be a strong predictor of receptive language ability, for example, syntax and linguistic concepts. Phonological working memory has been proven to be important for word recognition, and vocabulary development. Phonological working memory capacity has also been proven be related to the type of communication mode mainly used by the child at home and at school, that is, oral communication is associated with higher phonological working memory capacity [8].

The aim of this study is to provide information on whether an improvement in language skills might be achieved by improving working memory capacity in cochlear-implanted children to consider working memory training when planning habilitation programs for CI children.

Patients and methods

This study was carried out on 30 prelingual cochlear-implanted children (16 males and 14 females) at the Hearing and Speech Institute during the period from March 2016 to September 2016. This study was approved by the scientific and ethical committees of the Hearing and Speech Institute. All the parents signed consent for the study.

The inclusion criteria were as follows: (a) age range from 4 years, 8 months to 7 years, 6 months, (b) children who had received their CI since at age range from 1 year, 6 months till 2 years, (c) children with average intelligence, (d) children with below average working memory scores, and (e) all the children who could speak at least two word sentences. The exclusion criteria were as follows: (a) presence of any medical or psychological problem, (b) presence of a brain damage motor handicap, and (c) presence of any developmental disability or delayed developmental milestones.

All children were subjected to a protocol of assessment applied in the Hearing and Speech Institute Hospital. It included the following:

(1) Assessment of history, including the name of the child, date of birth, and date of implantation.
(2) Communicative assessment, which included the following:
    (a) Attention and eye contact.
    (b) Current means of communication (pointing, gestures, or verbal).
    (c) Imitation and speech reading ability was evaluated subjectively for sounds, syllables, words, and sentences.
    (d) Auditory discrimination for sounds, syllable, words, and sentences.
    (e) Language evaluation: using the Modified Preschool Language Scale-4 [9]. This test measures receptive, expressive, and total language age. The language improvement quotient [10] was used to compare between the rates of progress in language and was determined by calculating the difference between the language age in a period of time divided by the period of time. For example, language improvement quotient after 6 months=(language age in months after 6 months of therapy − language age in months before the therapy)÷6 months. In this way, we overcome the bias of age matching between the individuals in the study.
    (f) Speech assessment: including resonance, articulation, and general intelligibility.
    (g) Voice assessment.

All CI children were subjected to the Modified Preschool Language Scale-4 and to the working memory subtest measures in the Stanford–Binet Intelligence Scale ‘5th Arabic version’ [11] to assess the working memory. After 6 months, a post-therapy assessment was carried out using the same tests.

For the purpose of the study, the children were divided into two groups: group I included 17 CI children and they received communicative and rehabilitative therapy in addition to the working memory training program. Group II included 13 CI

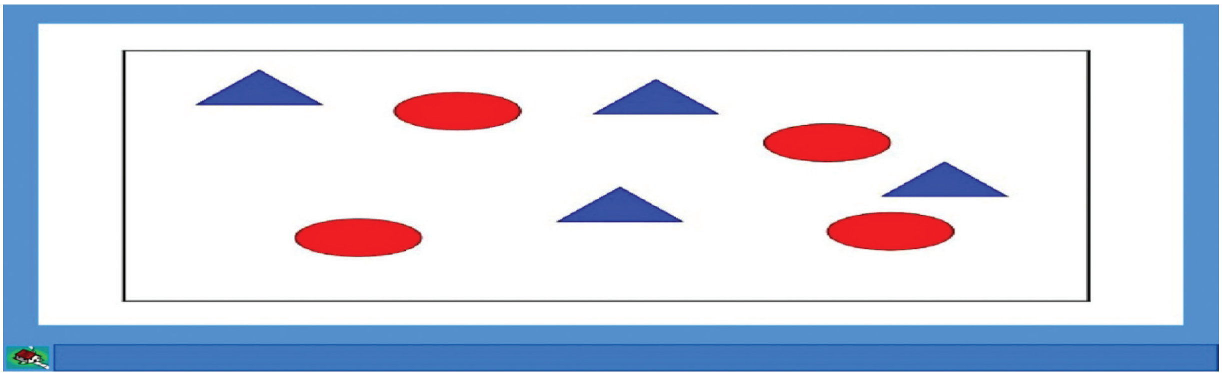
received the communicative rehabilitative therapy only. The communicative rehabilitation therapy comprised of regular language stimulation sessions in the form of three individual sessions/week. The duration of each session was about 30 min, followed by a 10 min meeting with the child's mother to demonstrate what was performed during the session, encouraging her to help the child at home. The computer-based working memory training program was three times/week for 20–30 min for 6 months [12].

The full version of the computer-based working memory training program (as presented in the Appendix) consists of 12 computer-based exercises including auditory, visuospatial, or combined auditory–visuospatial short-term, and working memory skills. It includes six working memory tasks and six short-term memory tasks. However, in the current study, six computer-administered working memory tasks were used: verbal and visuospatial working memory (three tasks for each). The six other short-term memory tasks were excluded because they were beyond the scope of the current study.

All six tasks required a consecutive recall of items and the storage and processing of verbal and visuospatial items. Three tasks were used in verbal working memory training: the listening span task and the counting span task and the backward digit span task. In the listening span task, the children listened to a sequence of sentences, and were asked to judge whether the sentences sounded true or false. They were also asked to repeat the last word in each set of sentences. In the counting span task (Fig. 1), the children were shown a figure with a series of dots and arrows and were asked to count the dots aloud, one by one, and then to recall the total number of dots in each series.

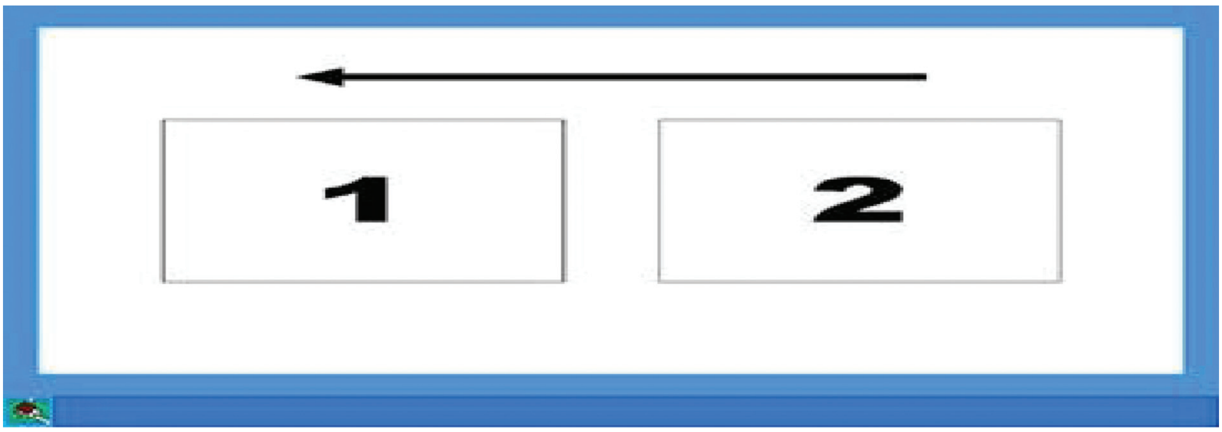
In the backward digit span task (Fig. 2), the children were presented with strings of auditory digits,

Figure 1



Counting span task.

Figure 2



Backward digit span task.

beginning with two digits and gradually increasing to nine digits, and were asked to recall each sequence of digits in reverse order. The visuospatial working memory tasks (nonverbal working memory tasks) used were the odd-one-out task, the Mr. X task, and the spatial span task. In the odd-one-out task, the children were presented with a sequence of similar shapes and one different shape and they were asked to specify which one was different from the others. In the Mr. X task, the children were presented with sets of two figures of a man with a red dot in one of his hands. One figure wore a yellow hat and the other wore a blue hat. The Mr. X in the blue hat had six possible positions. The children were asked to specify whether both Mr. Xs had the dot in the same hand. Meanwhile, in the spatial span task, the children were shown a series of series of geometric figures: one on the right side with a red dot and one on the left side without a dot. The children were asked to decide whether the figures were the same or different and to remember the location of the red dot.

All variables were treated as the continuous metric type. Summary measures given include mean and SD. Analysis was carried out using the Mann–Whitney test to assess the differences between the two groups and the Wilcoxon signed-rank test to assess differences in working memory within each group between the pretherapy and post-therapy results. *P* values less than 0.05 were considered significant. All analyses were carried out using IBM statistical package for the social sciences, version 24 (IBM: SPSS Inc., Chicago, IL, USA).

Table 1 Chronological age of children and age at the time of surgery

	Group I [mean (SD)]	Group II [mean (SD)]	*P* value*
Chronological age of children (months)	72.33 (13.28)	63.38 (7.43)	0.167
Age at the time of surgery (months)	26 (3.12)	24.75 (2.82)	0.37

*No significant difference in the composition of the two groups in the chronological age and the age at the time of the surgery.

Table 2 Language age quotients

	Group I [mean (SD)]	Group II [mean (SD)]	*P* value*
Receptive language quotient	2.9 (1.8)	0.94 (0.4)	0.04*
Expressive language quotient	1.4 (1.19)	0.41 (0.27)	0.34
Total language quotient	2.06 (1.55)	0.65 (0.42)	0.17

*There was a significant difference in the receptive language quotient, with a *P* value of 0.04.

Results

This study was carried out on 30 prelingual cochlear-implanted children (16 males and 14 females). The mean chronological age of the children of group I was 72.33 months (SD=13.28), whereas the mean chronological age of the children of group II was 63.38 months (SD=7.43). The results showed that there was no significant difference in the composition of the two groups in the chronological age and the age at the time of the surgery (Table 1).

In terms of the results of the language quotients, the mean receptive language quotient in groups I and II was 2.9 and 0.94, respectively. There was a significant difference in the receptive language quotient, with a *P* value of 0.04, as clarified in Table 2. The mean expressive language quotient in groups I and II was 1.4 and 0.41, respectively, whereas the mean total language quotient in groups I and II was 2.06 and 0.65, respectively. There was no significant difference in the expressive language quotient and the total language quotient between the two groups.

Table 3 indicates that there was no significant difference between the two groups in the pretherapy working memory variables (verbal, nonverbal, and total memory, with *P* values of 0.28, 0.07, and 0.09, respectively). However, all post-therapy working memory variables (verbal, nonverbal, and total working memory) showed significantly different results (*P*=0.03, 0.01, and 0.006, respectively) (Table 4).

The data in the following table (Table 5) show the comparison between the controls and the group receiving working memory training in terms of the pretherapy and post-therapy results. All three working memory variables (verbal, nonverbal, and total) showed a highly significant improvement following therapy (*P*=0.009, 0.008, and 0.008, respectively). For the controls, there was no to mild significance in the three variables (*P*=0.083, 0.046, and 0.041),

Table 3 Working memory results comparing the working memory group and the control group (before therapy)

	Group I [mean (SD)]	Group II [mean (SD)]	*P* value*
Verbal memory (before therapy)	3.22 (3.62)	1 (2.07)	0.28
Nonverbal memory (before therapy)	7.22 (1.72)	5.63 (1.69)	0.07
Total memory (before therapy)	74.78 (13.32)	64.88 (8.62)	0.09

*No significant difference between the two groups in the pretherapy working memory variables (verbal, nonverbal, and total memory), with *P* values of 0.28, 0.07, and 0.09 respectively.

suggesting that language exercises might improve working memory as well, albeit to a much smaller degree compared with working memory exercises (Figs 3–5).

Discussion

Working memory is crucial for speech and language development, and growth in working memory skills is closely linked to an improvement in language skills [2]. This study focuses on working memory and its effects on language improvement in CI children. However, only a few systematic studies have targeted a neurocognitive aspect other than language abilities in CI populations; the majority of these studies focused mainly on language abilities.

This study was carried out on 30 prelingual cochlear-implanted children (16 males and 14 females). The study results are based on both the Modified Preschool Language Scale-4 and the working memory subtest measures in the Stanford–Binet Intelligence Scale '5th Arabic version.'

Table 4 Working memory results comparing the working memory group and the control group (after therapy)

	Group I [mean (SD)]	Group II [mean (SD)]	*P* value*
Verbal memory (after therapy)	4.67 (3.97)	1.38 (2.07)	0.03*
Nonverbal memory (after therapy)	8.78 (1.64)	6.13 (1.89)	0.01*
Total memory (after therapy)	83 (13.5)	67.88 (10.2)	0.006*

*Significant difference in post-therapy working memory variables (verbal, nonverbal, and total working memory) with *P* values of 0.03, 0.01, and 0.006, respectively.

The children were divided into two groups: group I included 17 CI children who received communicative and rehabilitative therapy in addition to a working memory training program. Group II included 13 CI children who received communicative and rehabilitative therapy only.

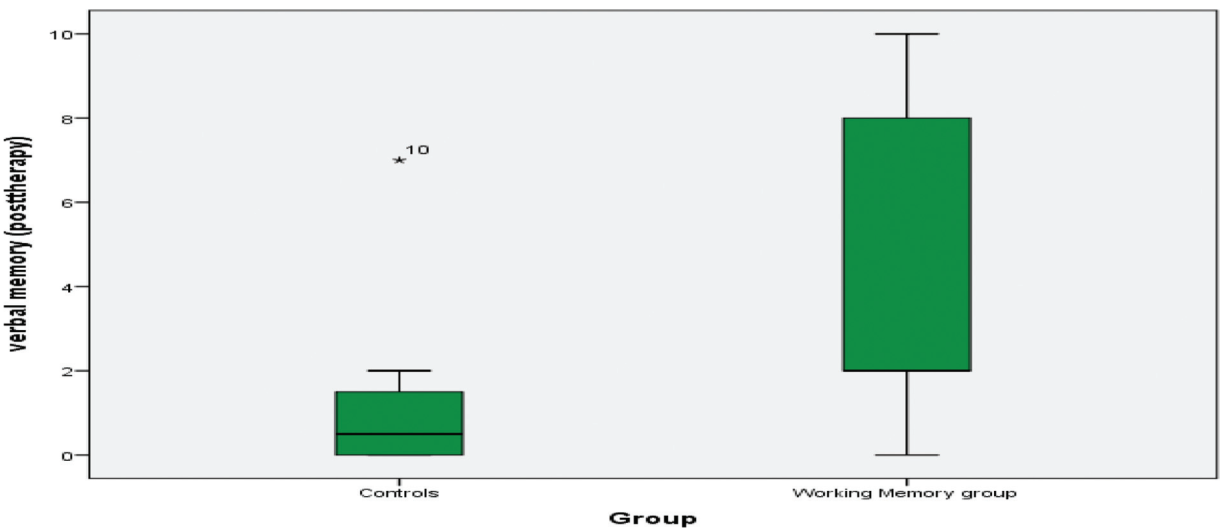
Differences in language quotient variables were significant in receptive language (0.04), but not significant in both expressive (0.34) and total language quotient (0.17). This result shows the effect of working memory training on language as there is a significant difference in receptive language between the study and the control group, whereas the expressive language did not show this significance. This indicates that the improvement in receptive language proceeds the improvement in expressive

Table 5 Comparison between two groups in pretherapy and post-therapy results

Groups	Subtests	Pretherapy [mean (SD)]	Post-therapy [mean (SD)]	*P* valuea
Working memory group	Verbal memory	3.22 (3.62)	4.67 (3.97)	0.009*
Controls	Verbal memory	1 (2.07)	1.38 (2.39)	0.083
Working memory group	Nonverbal memory	7.22 (1.72)	8.78 (1.64)	0.008*
Controls	Nonverbal memory	5.63 (1.69)	6.13 (1.89)	0.046*
Working memory group	Total memory	74.78 (13.32)	83 (13.5)	0.008*
Controls	Total memory	64.88 (8.62)	67.88 (10.2)	0.041*

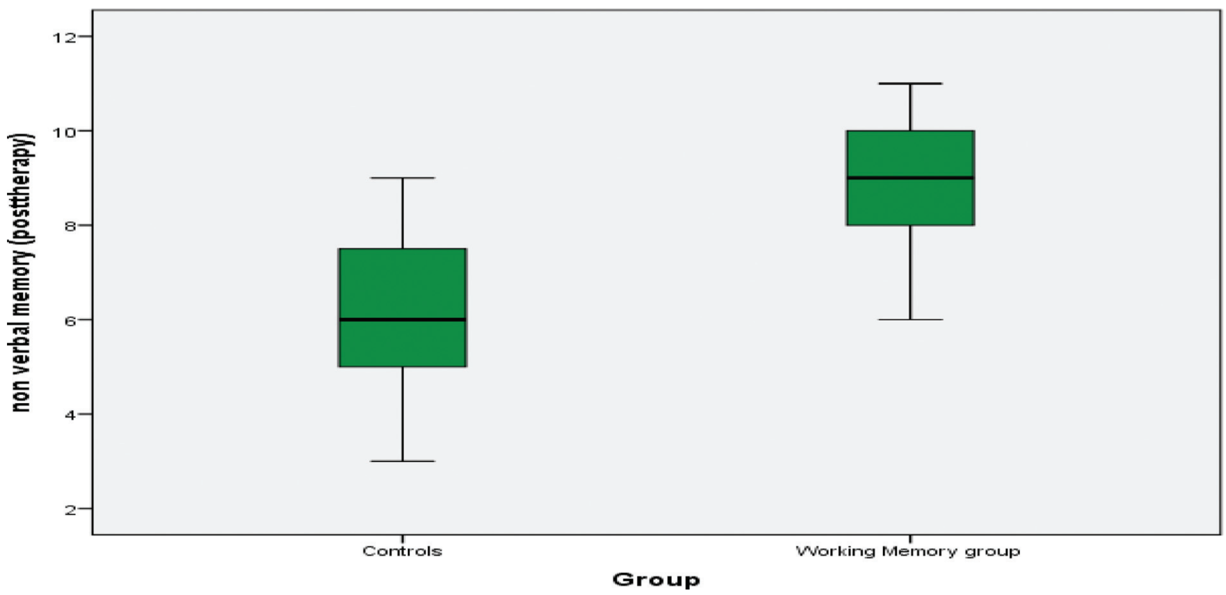
[a]Wilcoxon's signed-rank test. *Significant.

Figure 3



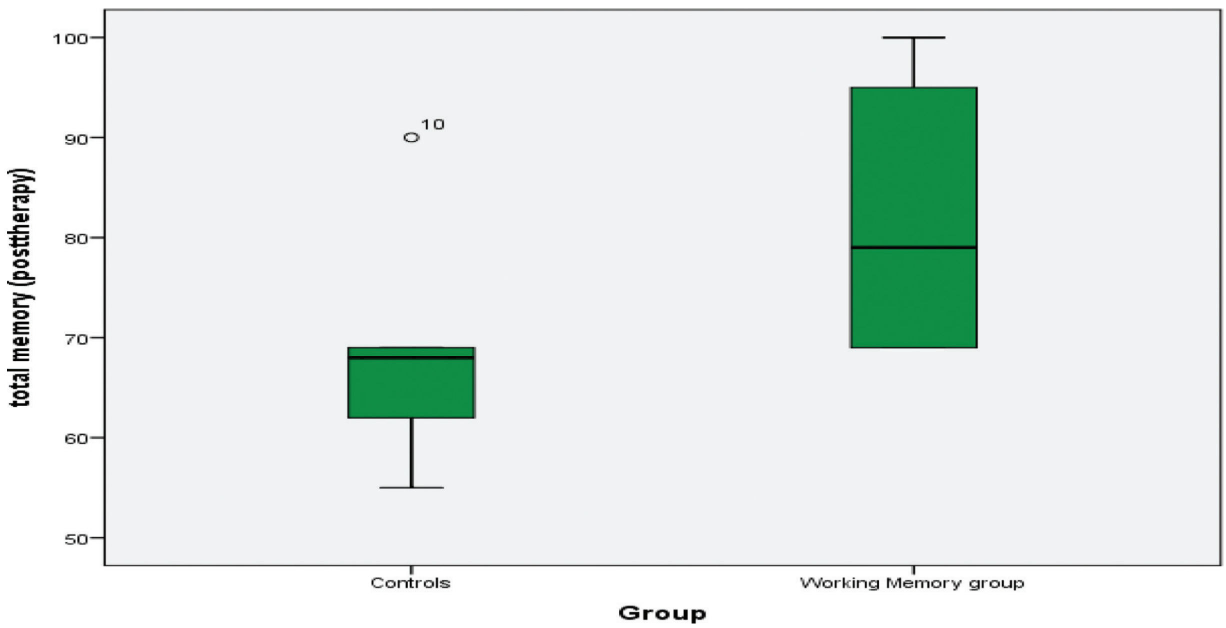
Comparison between two groups in verbal memory post-therapy results.

Figure 4



Comparison between two groups in nonverbal memory post-therapy results.

Figure 5



Comparison between two groups in total memory post-therapy results.

language as reported by many studies [13]. A study by Yoshinaga *et al.* [14] showed that receptive language skills were enhanced by training of working memory and language therapy, but with a delay in expressive language. The results in this study suggest that the outcome of language development depends partly on working memory capacity.

However, all post-therapy working memory variables (verbal, nonverbal, and total) showed significant results (*P*=0.03, 0.01, and 0.006, respectively), with the working memory group showing higher averages compared with the controls.

In terms of comparisons between the results before and after therapy (Table 5), all three working memory variables (verbal, nonverbal, and total) showed a highly significant improvement following therapy (*P*=0.009, 0.008, and 0.008, respectively). For the controls, there was no to mild significance in the three variables (P=0.083, 0.046, and 0.041), suggesting that language exercises might improve working memory as well, but to a much smaller degree compared with working memory exercises. Both groups showed a highly significant improvement in the language skills. This is expected due to the acoustic environmental access gained by the cochlear implanted children.

These results emphasize the relation between memory and language, and address the function of the phonological loop, which is the aspect of working memory that performs temporary storage of the auditory input. The results of our study also showed an improvement in verbal working memory capacity, nonverbal working memory capacity, and whole working memory in the sample of children with CIs, who received 6 months of a working memory training program plus communicative rehabilitation; these findings indicate that the improvement shown by participants on the actual trained tasks of the computer-based working memory training program extended beyond those tasks to other, more applied working memory tasks.This finding is in agreement with the study that investigated the efficacy of a computer-based training program for improving memory and language skills in a sample of children with CIs, which showed a statistically significant improvement on performance measures of verbal working memory (Digit Span) as well as visual-spatial working memory (Spatial Span) after training on the Cogmed tasks [15]. In addition, parents reported an improvement in participants' day-to-day working memory and attention. Mohandes *et al.* [16] documented a strong positive correlation between total memory scores and language age in cochlear-implanted children and suggested that intervention for memory and sequential processing skills may be appropriate and effective for children with CIs who are experiencing language delays following cochlear implantation.

Conclusion

Working memory training specifically addressing the basic underlying verbal working memory deficits of children with CIs improves their memory and language skills. Working memory therapy may be expected to have effects that generalize well beyond the trained working memory tasks and transfer to nontrained language perception and memory tasks. Therefore, training of working memory in the rehabilitation program for CI children is recommended to achieve a better language outcome.

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Nil.

Conflicts of interest

There are no conflicts of interest.

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