Auditory short-term memory in children with cochlear implant

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Objective
The aim of this study was to assess short-term auditory memory in children with cochlear implant and to assess the possible correlation of their language ages with their memory scores to consider memory training during rehabilitation program for cochlear-implanted patients.

Patients and methods
Sixty-one Egyptian children were included in this study. Thirty prelingual deaf children implanted with the nucleus multichannel cochlear implant were included. Their ages at the time of implantation ranged from 4 years to 4 years 11 months. All of the children had normal intellectual abilities. All cases were selected from Wadi El Neel Hospital where they received their aural-oral rehabilitation program for 1 year. A total of 31 normal children of matched sex and age were selected as a control group. A battery of auditory short-term memory assessments for Arabic-speaking children were applied to all children. An Arabic language test was also applied.

Results
A significant defect in short-term auditory memory in cochlear-implanted children as compared with controls was proven. A positive correlation between short-term auditory memory and their language ages was found.

Conclusion
The study revealed defective short-term auditory memory in cochlear-implanted children. This defect is more evident in cochlear-implanted children with poor language skills.

Keywords:
acquisition, digit span, language, language age, short-term auditory memory

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Introduction

Cochlear implants (CIs) provide profoundly deaf children access to sound and spoken language during a period of dynamic brain plasticity, resulting in significant gains in speech and language skills [1]. A bulk of studies on CIs have been carried out by audiologists and hearing scientists who have been concerned with the sensory coding of speech by the peripheral nervous system [2,3]. The focus of those studies emphasized on the study of audiologically based outcome measures.

To gain a better understanding of what children are learning through their CIs, it is necessary to approach the problem from an entirely different theoretical perspective and look more closely at the content and flow of information within the processing system and how it changes over time.

Researchers have begun to examine the effects of CIs on specific aspects of language development. One very important area of research on language development concerns the nature of the child's phonological system, which encodes and represents the inventory of sounds the child has acquired and the rules used to produce the sound contrasts of the ambient language [4,5].

At this time, not being extensively studied in deaf children with CIs, we know very little about complex working memory and short-term auditory memory (STM) systems that might play significant and distinct roles in supporting the acquisition of knowledge. These systems are considered a key factor in acquiring new words and producing spoken language using phonological knowledge previously stored in memory [6,7].

STM, which helps the individual to follow, retain, and integrate a stream of auditory information [8], is considered an important factor contributing to receptive speech development in young children, in addition to auditory perception and processing and other higher cortical functions such as intelligence, cognition, and attention. STM is extremely important for understanding words and sentences both in normal hearing and hearing-impaired children. It has been recognized that degraded speech signal such as perceived by CI users largely affects immediate memory test performance [9]. It is especially

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important for young prelingual deaf children, because it can significantly influence the development of receptive and expressive speech [10]. Deficit of auditory memory could be responsible for impaired sentence comprehension. It is very important to follow and improve auditory memory in hearing-impaired children during rehabilitation [11].

Objectives of the study

The objectives of this study were to assess STM in congenitally deaf children with CIs and to correlate total memory scores of cases with their language age to determine the need for considering memory training when planning habilitation program for CI children.

Patients and methods

Sixty-one children were included in this study. Of them, 31 served as a control group and the other 30 (17 girls and 13 boys) had bilateral congenital deafness. The controls and the cases were sex-matched and age-matched. The study was performed between May and November 2014. This study has been approved by a research ethics committee.

All children had normal intellectual capacity. All prelingual deaf children were implanted with a nucleus multichannel CI at Wadi El Neel Hospital where they received their aural-oral rehabilitation program for 1 year comprising regular language stimulation sessions in the form of three individual sessions/week. The duration of each session was about 30 min, followed by 10 min meeting with the mother of the child to demonstrate what was performed during the session, encouraging her to help the child at home. Language ages of selected children ranged from 2 to 3 years according to the Arabic language test. All children were Egyptian. The children included in the study received their CI at age ranging from 4 years to 4 years 11 months. The exclusion criteria for preoperative selection were as follows: (a) having medical or psychological conditions that contraindicate undergoing surgery; (b) having developmental disabilities and delayed developmental milestones; and (c) having brain damage motor handicap.

All CI children were subjected to protocol of assessment applied in kasr Al Aini hospital. It included the following:

(1) History taking, including name of the child, date of birth, and date of implant use
(2) Communicative assessment:
    (a) Attention and eye contact
    (b) Current mean of communication (pointing, gestures, or verbal)
    (c) Imitation and lip-tracking ability for sounds, syllable, words, and sentences
    (d) Auditory discrimination for sounds, syllable, words, and sentences
    (e) Receptive language for semantics, syntax, and understanding sentences with variable complexity
    (f) Expressive language, including vocabulary size, semantics, and syntax. For Receptive and Expressive language skill assessment, the Arabic Language test was used [12]
    (g) Speech assessment, including resonance, articulation, and general intelligibility
    (h) Voice assessment.

The CI children and normal children were subjected to STM testing battery [13], which was previously collected from previous reviews and adapted to Arabic language and then applied on 120 normal Egyptian Arabic-speaking children. The assessment battery was held in a quiet sound proofing place for about 20 min.

The battery of tests included the following items.

Phonological storage

Simple span tests were used to assess STM as it requires only storage, maintenance, and recall of verbal information without any manipulation (Appendix).

Digit span

The Digit span test is one of the tasks most often used to measure STM and a widely used measure of phonological loop [14,15]. The administration procedure was as follows: the assessor read aloud a series of digits at a rate of one digit per second and then asked the child to recall the series of digits in the same order as presented. The digits were chosen from 1 to 9. The Digit span consisted of seven series. If the child failed in one series, a second trial of a series of the same length was administered. The number of digits in the initial series was two and increased by one in each successive series up to eight digits.

Scoring

The child received a score of 1 for each series of digits recalled in the same order of presentation and received 0 for series of digits not recalled, or not recalled in the same order of presentation. Total score was equal to 7.

Letter sequences recall

The idea of the test was originally developed by Blankenship and colleagues [16,17]. The administration procedure was as previously administered in the digit span task.

The letters were chosen from Arabic Alphabet and the sequences consisted of seven series. The letters were administered literally. If the child failed in one trial, a second trial was administered of the same series length. The number of letters in the initial series was two and increased by one in each successive series up to eight letters.

Scoring

The child received a score of 1 for each set of letters recalled in the same order of presentation and received 0 for a set of digits not recalled in the same order of presentation. Total score was equal to 7.

Word set recall

The idea of the test was obtained from a study conducted by Baddely *et al.* [18].

Recall of short versus long word sets

This test was conducted to assess the efficiency of retrieval of phonological sequences of different lengths [19]. Words were selected according to the phonological complexity (number of syllables in each word).

Recall of similar versus dissimilar word sets

This test was conducted to assess the efficiency of retrieval of phonological sequences with different rhyming.

The word sets were presented verbally by the examiner at a rate of one word per s and were carefully selected to denote common and familiar objects like (عين - قطة - شمس) for short word sets. The children had to remember the words in the same order in which they were presented and repeat them back to the experimenter immediately after each sequence. Sequences were increased from two to eight words. For a trial to be considered correct, all words in that sequence had to be remembered and in the correct order. If the child failed in recalling a certain sequence, or did not produce the words in the correct order, the child would have another trial of a different word sequence but with the same number of items produced in the trial he or she failed. It is worth noting that the score was given only when the child produced the correct words with proper sequence administered regardless of whether or not the child produced the words with proper articulation, as assessing memory (assessing the ability of the child in keeping in his memory, for example, three items as in case of a set in three word series) not phonology was the aim in this study.

Scoring

The child received a score of 1 for each set of words recalled in the same order of presentation and received 0 for the set of words not recalled in the same order of presentation. Total score was equal to 7 for each group of word sets.

Nonword repetition

A nonword repetition test is frequently used as a pure measure of phonological loop ability [20]. The test is composed of 10 bisyllabic, 10 trisyllabic, and 10 tetrasyllabic nonwords. The child under study was given the following instructions: 'I am going to say some silly made-up words to you. Say them after me exactly the way that I say them. You will have to listen carefully, because I will say the words only once and you should imitate the items to the best of your ability'. They were also instructed that they should guess if they were uncertain.

Scoring of nonwords here depended on the ability of the children to repeat the same number of syllables as the target nonword.

Two examples of nonwords were given by the assessor and the child was asked to repeat each. Once the child appeared to be comfortable with the test, the nonwords were presented and the child was asked to recall each nonword immediately after presentation.

Scoring

The total score was determined by the number of nonwords recalled correctly depending on recall number of syllables as presented in the target nonwords.

As transpositions are considered to be more severe than that of substitutions in normal child language development, substitution of consonants was accepted. Total score was equal to 10 for each nonword length.

Results were compared across subgroups of children and subtests of STM. Data were statistically described in terms of means ± SD, frequencies (number of cases), and percentages, when appropriate. Comparison of quantitative variables between the study groups was made using Student's *t*-test for independent samples. Correlation between various variables was accomplished using Pearson's moment correlation equation for linear relation. A *P*-value less than 0.05 was considered statistically significant. All statistical calculations were carried out using computer programs: Microsoft Excel 2007 (Microsoft Corporation, New York, New York, USA) and statistical package for the social science (SPSS Inc., Chicago, Illinois, USA), version 15 for Microsoft Windows.

Results

A *t*-test for equality of means revealed the following:

(1) A significant difference was found between the cases and controls in the mean of total memory scores ($P < 0.001$)
(2) A significant difference was found between cases and controls as regards bisyllabic nonword repetition, trisyllabic nonword repetition, and tetrasyllabic nonword repetition ($P < 0.001$)
(3) No significant difference was found between male and female patients in the mean of total memory scores
(4) Total memory scores increased with higher language age
(5) Correlation analysis showed a positive relation of auditory short-term memory with language age.

Discussion

STM capacity has been shown to play a significant role in the acquisition of language during childhood, both in maternal language development and when learning foreign languages [21]. It has therefore been referred to as a language learning device [22] and is one of the best predictors of language impairment in young hearing children [23].

The memory span procedure, evaluating how many items a person can repeat back in sequence, has been widely used in developmental studies as a prototype for investigating STM development. There are several reasons to justify this preference: first, it is simple enough to be comprehensible for very young children; second, it is a developmentally sensitive index, considering that it increases steadily during the ages of 3 to 10 years [24]; and, finally, research on the mechanisms involved in performing this task is ecologically relevant, taking into account its relation to performance on complex tasks involving comprehension and problem-solving [25], or to academic achievement [26] and its widespread use in intelligence testing [27].

In the current study, some precautions were taken into consideration when developing nonword repetition tasks to avoid any influencing factors on the performance of children. Nonwords were constructed to be away from any similarity with familiar words as the lexical familiarity of the nonword has an impact on repetition skills – that is, when nonwords are similar to real words they are more easily repeated by children as this similarity taps into the long-term store – and earlier lexical knowledge supports more accurate and rapid repetition. In child language research, imitations is considered to be an important milestone in the development of phonological memory [28]. This seems to be true for children with CIs in this study.

Scoring in this study for nonword repetition depended on suprasegmental aspects (number of syllables recalled) rather than segmental aspects as has been taken into consideration in previous studies such as the study by Carter *et al.* [29], in which the main concern in this study was tapping memory rather than phonological analysis of the CI children's speech production.

This study showed lower STM in CI children as compared with normal children, which could be attributed to limitations on their processing capacity (Table 1) and also to the peripheral and central differences in neural function between the CI children and their corresponding normal children. These differences are likely to be found among the CI children and are possibly responsible for the wide range of variability observed in outcome and benefit following implantation.

This finding is in agreement with that reported in previous studies such as the study by Wass *et al.* [30], who stated that, although prelingually deaf children receive a CI as a treatment for their profound hearing loss, they do not simply have their hearing restored at the auditory periphery.

More significantly, after implantation they begin to receive substantial auditory stimulation to specialized areas of their central nervous system that are critical for the development of spoken language and specifically for the development of phonological processing skills that are used to rapidly encode and process speech signals. Although the children with CI receive auditory input, hearing is not restored to normal levels. Therefore, the auditory cortex receives a degraded signal hampering the development of phonological representations in long-term memory, which are thus likely to be imprecise [31]. Consequently, systems other than those related to verbal auditory processing also will be affected (i.e., the imprecise phonological representations). A long lack of auditory input may also cause the cells predisposed for hearing to develop other functions instead of being unused, resulting in a neural reorganization of the auditory system [32], and thus affecting speech and language skills after implantation, which may develop in an atypical manner.

This study revealed lower performance of CI children on tasks of nonword repetition as compared with the

Table 1 Comparison of total memory scores between cases and controls

Total memory score	Cases		Controls		*P* value
	Mean	SD	Mean	SD	
	20.233	9.8775	47.129	5.7836	0.000

SD, standard deviation.

control group (Table 2). This could be attributed to the nature of the nonword task. Although nonword repetition appears at first glance to be a simple information processing task, in actuality it is considered a very complex linguistic task that requires the child to perform well on each of the following individual component processes, including speech perception, phonological encoding and decomposition, active verbal rehearsal in working memory, retrieval and phonological reassembly, and finally phonetic implementation and speech production. This finding also augments the limitation in processing the capacity of CI children.

Comparison between male and female patients based on their total memory scores revealed insignificant differences (Table 3), and this could be attributed to the differences between male and female patients in relation to cognitive performance, which is subtle and, if it exists, it needs to be demonstrated by studies carried out on a large scale.

This is in agreement with the findings of many recent studies that compared performance in cognitive abilities across sex. Harness *et al.* [33] found that male and female patients are much more similar psychologically than are different. Therefore, any sex differences are typically exaggerated and not practically significant [34].

Comparison between cases with language age less than 2 years and 6 months and those higher than 2 years and 6 months revealed higher total memory scores with increased language age (Table 4). In addition, a strong positive correlation was found between total memory scores and language age (Table 5). This result emphasizes the strong relation between memory and language and addresses the function of the phonological loop, which is the aspect of working memory that makes a temporary store of auditory input [23]. The amount of input a person can hear and then report back can be seen as a rough measure of the capacity of the phonological loop. In terms of language acquisition and comprehension, it is natural to assume that the capacity of the phonological loop will have some kind of relationship with learning success, simply by virtue of being a major point of language input and a limiting factor on real time language processing. If a person can only hold a short amount of material in his phonological loop, he or she will necessarily have difficulties in processing longer or more complex strings of language (Figs 1 and 2).

Table 2 Comparison of results of nonword repetition test between cases and controls

	Bisylabic NW		Trisyllabic NW		Tetrasyllabic NW		*P* value
	Mean	SD	Mean	SD	Mean	SD	
Cases	6.800	3.4180	4.100	2.9402	1.267	1.3880	0.000
Controls	9.839	0.4544	8.968	1.0160	8.161	1.3686	

nw, nonword; SD, standard deviation.

Table 3 Comparison of the mean of total memory scores between male and female patients

Total memory score	Male patients		Female patients		*P* value
	Mean	SD	Mean	SD	
	21.231	7.2704	19.471	11.6518	0.637

SD, Standard deviation.

Table 4 Comparison of the mean of total memory scores between two LA categories

Total memory score	Cases of LA less than 2 years, 6 months		Cases of LA more than 2 years, 6 months		*P* value
	Mean	SD	Mean	SD	
	16.826	8.3157	31.429	5.2236	0.000

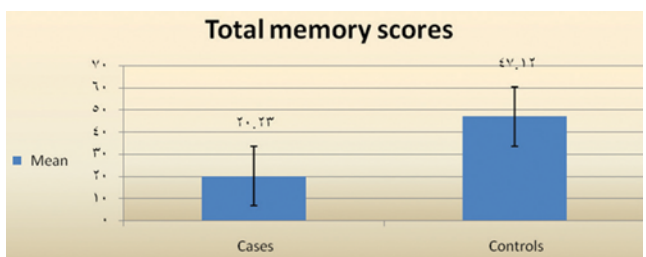
LA, language ages; SD, standard deviation.

Table 5 Correlations of total memory scores with language age

Total memory score	*r*-value	*P* value
Language age (years)	0.563**	0.001

**Highly significant

Figure 1



Comparison of the mean of total memory scores between cases and controls.

Conclusion

The study found defective auditory STM in CI children with a strong positive correlation between language development and STM. The findings of the study suggest considering training of STM in the rehabilitation program for CI children to reach a better language outcome.

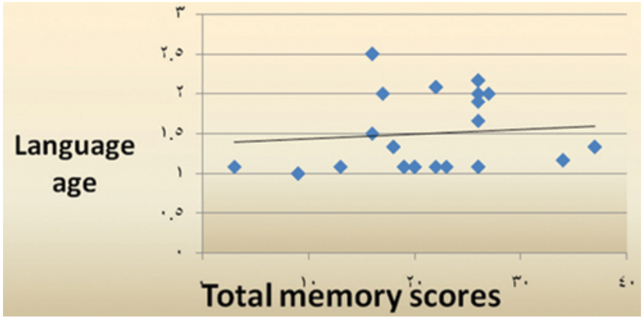
Financial support and sponsorship

Nil.

Conflicts of interest

There are no conflicts of interest.

Figure 2



Correlation of total memory scores with language age in cochlear-implanted children.

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Appendix

Working memory recall tests:

First Trial of digit span:

٨,٥
٤ ,٧ ,٩
٣,٢,٨,٥
٩,٧ ,٨,٣,٦
٧,١,٩ ,٨ ,٦,٢
١,٥ ,٩,٧,٣,٨,٥
٨,٤,١,٣ ,٧ ,٩ ,٦,٢

First Trial of Letter sequences:

ك -و
س -ع-ك
ه -ك -خ-ت
ك -س - ب -و -ي
ه -س -ك -و - ل -ق
خ- ه -و -ك -ق - ح -س
ح -و - ن -ه -ك -ر - ق -س

First trial of recall of short word sets:

ةربا -رمق
رطق -بلك -ةسوك
ليف -راج - يسرك -ديا
عيبر -ليمع -باب -ريرس - رون
ءوب -راف -كابش -ةروص -رون -بحاص
كيد -سمش -دارب -ةطق -موت -رامح - نيع
ةلس – ةطنش -ةلجع -ةخرف -ياش -ةدرو - ةطب -رزج

First trial of recall of long word sets:

ةكوراب -ةدايع
سيبوتأ -ةيسمش -نويزفيلت
حاولأ -بعالم -قيدانص -كيبابش
تامالع -ةروسام -تايبرع -قاروأ -زيوارب
ديجاجس -بكارم -شيكاوش -نيكاكس -رطاسم -ليدانم
-بيلاود -رتويبمك -زاجتوب - ةزيبارت -ةروبس ريماسم -ملالس
-ةحيرست -حيتافم -ةرينوفوش -سطاطب -ةيلديص نيتاسف -ةسوبسب -فوشرخ

First trial of recall of similar word sets:

لين -ليف
ليبن -ليبس -ليباه
ءانف -ءاطع - ءالو -ءانس
ءارش -ءاعد -ءاني م -ءامس -ءاسن
حابص -حابر -حاشو -حالصا -حاجن - حاتفم
دودح - دورش -دودس - دورو– دوقنع -دودو - دونع
دنع -درب -دس -دعو - دو -دن -دهع -دهف

First trial of Recall of dissimilar word sets:

ةيابوك - باب
ةطنش -ناصح -ةعاس
كنب - ةيبرع -ديا -ةعمش
نيع -ةوكم -ةزيبارت -ناتسف -ريرس
لسع - ةزوم -ةبمل -قبط -نويزفيلت - دارب
ةرامع -دوماع - ةربا -نوفيلت -ةنوركم -ةقلعم -ةعامس
باكرم -لمر -نولطنب -ةبد -رطق -ةرانص -ةكوش -مازح

Examples of Non-Word Repetition test:

Bisyllabic nonwords: فوتشاك

Trisyllabic nonwords: نوبامروف

Tetrasyllabic nonwords: توكاميشاق