Abdelhamid and Fadel
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Age as an important variable that affects auditory and language results after cochlear implant

Nihal Hisham Abdelhamid[1*] and Hanaa Fadel[1]

Abstract

Cochlear implant (CI) benefits deaf children's speech perception, language development and speech production. Early fitting of an implant results in improved outcomes. Over a period of more than 3 decades, cochlear implantation (CI) is firmly known as safe and effective treatment for children with bilateral severe to profound sensorineural hearing loss (SNHL) who develop minimal or no benefit from conventional hearing aid use. The primary aim of CI is to improve auditory perception of the child and hence the spoken language. The development of functional spoken language would be the major long-term benefits of CI. Children who received a cochlear implant before a real delay in spoken language development (i.e., between 12–16 months) were more able to achieve age-appropriate spoken language. These results strengthen the idea of doing cochlear implantation before 24 months of age, especially for children with a better ear aided pure tone with average thresholds greater than 65 dB prior to surgery.The main aim is to study the effect of age on CI patients results by applying simple questioners on 31 CI children, that are easy to assess the auditory perception and discrimination as an important prerequisite for language development.

Results There was an inverse correlation between; age at CI, categories of auditory performance (CAPS), and meaningful auditory integration scale (MAIS) scores. While; there was direct correlation between MAIS & CAPS scores.

Conclusions The auditory perception development after CI in children being 3 years old or younger is much better than the older children which would be reflected on their speech perception and acquiring their 1st word and sentence, but language development did not differ between both groups for this period of follow up. With a need of further detailed full language aspects assessment and follow up to ensure these results.

Keywords Cochlear implant, Language development, Hearing impairment, Auditory perception

Background

Cochlear implant (CI) benefits deaf children's speech perception, language development and speech production. Early fitting of an implant results in improved outcomes [1].

Over a period of more than 3 decades, cochlear implantation (CI) is firmly known as safe and effective treatment for children with bilateral severe to profound sensorineural hearing loss (SNHL) who develop minimal or no benefit from conventional hearing aid use. The primary aim of CI is to improve auditory perception of the child and hence the spoken language. The development of functional spoken language would be the major long-term benefits of CI [2].

Children who received a cochlear implant before a real delay in spoken language development (i.e., between 12–16 months) were more able to achieve age-appropriate spoken language. These results strengthen the idea of doing cochlear implantation before 24 months of age, especially for children with a better ear aided pure tone

*Correspondence:
Nihal Hisham Abdelhamid
Rulucky_23@hotmail.com
[1] Phoniatric and Audiological departments, Hearing and Speech Institute, Giza, Egypt

with average thresholds greater than 65 dB prior to surgery [3].

The main aim is to study the effect of age on 31 CI patients results at the hearing and speech institute, Egypt by applying simple questioners that are easy to assess the auditory perception and discrimination as an important prerequisite for language development. The children divided into two groups, group A: CI before age of 3 years and group B: CI after the age of 3 years.

Methods

Thirty one children diagnosed with bilateral severe to profound sensorineural hearing loss (SNHL) that underwent CI at hearing and speech institute Egypt. Inclusion criteria: (1) bilateral severe to profound SNHL and had received cochlear implant, (2) onset of hearing loss before age of 6 months, (3) age was less than 10 years old, and (4) received language therapy and auditory rehabilitation after CI (5) satisfactory auditory response by aided free field.

Exclusion criteria: (1) congenital anomalies of the inner ears diagnosed by MRI, (2) children below average mentality less than 85 intelligent quotient, and (3) children diagnosed as auditory neuropathy.

The children divided into two groups, group A: CI before age of 3 years (15 patients) and group B: CI after the age of 3 years (16 patients). Every patient has been assessed to ensure satisfactory outcome of the CI by aided free field audiometry using sound treated room and by applying pure tones at frequency range:500 Hz-4 kHz through loudspeaker at 45 degrees azimith, the audiometer used was AC 40 ineteracoustics, Denimark. language and auditory perception assessed by applying simple questioners with parents under the guidance and direct observation of the clinician to assess speech and sound perception, also language assessment was done for these children by Modified Preschool Language Scale, fourth edition (PLS-4) Arabic version [4].

Auditory perception was evaluated 18 months post CI, the children were assessed by the Arabic version of categories of auditory performance (CAP) and meaningful auditory integration scale (MAIS) [5] (Figs 1 and 2).

Ethical approval was obtained for the current study from the ethics and research committee of the National Hearing and Speech Institute, Egypt, and the parents of the patients signed a fully written informed consent before enrolment in the study.

Results

The collected data was revised, coded, tabulated and introduced to a PC using Statistical package for Social Science (SPSS 15.0 for windows; SPSS Inc, Chicago, IL, 2001). Data was presented and suitable analysis was done according to the type of data obtained for each parameter.

We found that the number of females for age > 3 years were 12 with a percentage of 75%, which was higher than that for age ≤ 3 years which was 5 females (33.3%). While; the number of males for age ≤ 3 years was 10(with a percentage, 66.7%) that was higher than that for age > 3 years (25%). Those differences; were statistically significant (Table 1).

There were no statistically significant differences between gender regards age at CI, CAPS & MAIS (Table 2).

The mean age at CI for > 3 years; was higher than that for ≤ 3 years. While; the mean CAPS & MAIS scores for ≤ 3 years, were higher than those for > 3 years. Those differences were, statistically highly significant (Table 3).

The percentage of CAPS score [3] for children > 3 years was (56.3% = 9 children); that was higher than that for ≤ 3 years (0%).While; the percentage of CAPS score [5] for children ≤ 3 years was 8(53.3%); which was higher than that for > 3 years (0%).Those differences were; statistically highly significant (Table 4).

The percentage of MAIS score range (1–20) for children > 3 years (81.3% = 13 children); was higher than that for children ≤ 3 years (0%). While; the percentage

Categories	Description
Category 0	No awareness of environmental sounds
Category 1	Awareness of environmental sounds
Category 2	Responds to speech sounds (e.g. 'go')
Category 3	Identification of environmental sounds
Category 4	Discrimination of some speech sounds without lipreading
Category 5	Understanding of common phrases without lipreading
Category 6	Understanding of conversation without lipreading
Category 7	Can use the telephone with a known speaker

Fig. 1 CAP

Categories	Description
Category 1	Does the child consistently ask to have the hearing aids/cochlear implant system put on, or put it on himself, without being told?
Category 2	Does the child regularly report and/or appear upset if the hearing aids/cochlear implant system is non-functioning for any reason?
Category 3	Does the child regularly respond to his name in quiet when called auditorially only with no visual clues?
Category 4	Does the child regularly respond to his name in the presence of background noises when called auditorially only, with no visual clues?
Category 5	Does the child regularly alert to environmental sounds (doorbell, telephone) without being prompted or told to listen?
Category 6	Does the child alert to auditory signals spontaneously when in a new environment (an unfamiliar shop while taking a walk, in someone else's home) asking 'What is that sound' or indicating 'I can hear something'?
Category 7	In the classroom, do you think that the child can recognize auditory signals that are part of his school routine, such as bell, whistle?
Category 8	Does the child show the ability to discriminate between two speakers by listening alone (mother v/s father, for example)?
Category 9	Does the child seem to know the difference between speech and non-speech stimuli, when listening alone? For example, if someone speaks behind him, does he recognize it as speech by saying 'What did you say?' or 'Did someone say something?'
Category 10	Does the child associate vocal tone (anger, anxiety, excitement) with its meaning, based on listening alone?

MAIS scoring system: Never '0', Rarely '1', Occasionally '2', Frequently '3', Always '4'

Fig. 2 MAIS

Table 1 Comparison between age groups regards gender

	≤ 3 years (*n* = 15)	> 3 years (*n* = 16)	Total (*n* = 31)	X^2	*P* Value	Sig
Male	**10(66.7%)**	**4(25.0%)**	**14(45.2%)**	**5.43**	**0.032**	**S**
Female	**5(33.3%)**	**12(75.0%)**	**17(54.8%)**			

Fisher's exact chi-square test

Table 2 Comparison between gender regards age at CI, CAPS & MAIS

		N	Mean	SD	Median	Range		t	*P* Value	Sig
						Min	Max			
Age at CI	**Male**	**14**	**3.1**	**1.0**	**3.0**	**1.5**	**5.0**	**1.97**	**0.058**	**NS**
	Female	**17**	**4.0**	**1.3**	**3.8**	**2.1**	**6.6**			
CAPS	**Male**	**14**	**3.9**	**1.2**	**4.0**	**2.0**	**5.0**	**0.98**	**0.337**	**NS**
	Female	**17**	**3.5**	**1.1**	**3.0**	**2.0**	**6.0**			
MAIS	**Male**	**14**	**29.0**	**8.1**	**33.0**	**12.0**	**36.0**	**2.03**	**0.052**	**NS**
	Female	**17**	**23.4**	**7.2**	**20.0**	**15.0**	**36.0**			

Independent-Samples T test

Table 3 Comparison between age groups regards age at CI, CAPS & MAIS

		N	Mean	SD	Median	Range		t	*P* Value	Sig
						Min	Max			
Age at CI	**≤ 3yrs**	**15**	**2.6**	**0.4**	**2.6**	**1.5**	**3.0**	**7.68**	**< 0.001**	**HS**
	> 3yrs	**16**	**4.6**	**0.9**	**4.4**	**3.3**	**6.6**			
CAPS	**≤ 3yrs**	**15**	**4.7**	**0.6**	**5.0**	**4.0**	**6.0**	**8.10**	**< 0.001**	**HS**
	> 3yrs	**16**	**2.8**	**0.7**	**3.0**	**2.0**	**4.0**			
MAIS	**≤ 3yrs**	**15**	**33.4**	**3.3**	**35.0**	**24.0**	**36.0**	**12.3**	**< 0.001**	**HS**
	> 3yrs	**16**	**18.9**	**3.3**	**20.0**	**12.0**	**24.0**			

Independent-samples T test

Table 4 Comparison between age groups regards CAPS scores

CAPS	≤3 years (*n* = 15)	>3 years (*n* = 16)	Total (*n* = 31)	X^2	*P* Value	Sig
1	**0**	**0**	**0**	**26.04**	**< 0.001**	**HS**
2	**0**	**5(31.3%)**	**5(16.1%)**			
3	**0**	**9(56.3%)**	**9(29.0%)**			
4	**6(40.0%)**	**2(12.5%)**	**8(25.8%)**			
5	**8(53.3%)**	**0**	**8(25.8%)**			
6	**1(6.7%)**	**0**	**1(3.2%)**			
7	**0**	**0**	**0**			

Fisher's exact chi-square test

Table 5 Comparison between age groups regards MAIS scores

MAIS	≤3 years (*n* = 15)	>3 years (*n* = 16)	Total (*n* = 31)	X^2	*P* Value	Sig
1–20	**0**	**13(81.3%)**	**13(41.9%)**	**30.3**	**< 0.001**	**HS**
21–25	**1(6.7%)**	**3(18.8%)**	**4(12.9%)**			
26–30	**1(6.7%)**	**0**	**1(3.2%)**			
31–35	**8(53.3%)**	**0**	**8(25.8%)**			
36–40	**5(33.3%)**	**0**	**5(16.1%)**			

Fisher's exact chi-square test

Table 6 Correlation between age at CI &MAIS, CAPS

		CAPS	MAIS
Age at CI	***R***	**-0.696**	**-0.780**
	P Value	**< 0.001**	**< 0.001**
	Sig	**HS**	**HS**
MAIS	***R***	**0.843**	
	P Value	**< 0.001**	
	Sig	**HS**	

Pearson correlation

Table 7 Comparison between both groups regarding the age of acquisition of first word and first sentence

	Group A CI ≤ 3 years	Group B CI > 3 years	T test		
	Mean ± SD	*Mean ± SD*	*T*	*P-value*	*Sig*
Age of acquisition of first word (in years)	2.81 ± 1.04	4.05 ± 2.11	− 2.87	0.006	S
Age of acquisition of first sentence (in years)	3.52 ± 1.61	5.41 ±	− 2.21	< 0.001	S

Table 8 Comparison between both groups regarding receptive, expressive and total language ages by Modified (PLS-4); Arabic version

Language age in years (Mean ± SD)	Group A CI ≤ 3 years	Group B CI > 3 years	T test		
	Mean ± SD	*Mean ± SD*	*T*	*P-value*	*Sig*
Receptive	3.01 ± 1.19	2.75 ± 0.80	1.05	0.294	NS
Expressive	2.63 ± 0.94	2.36 ± 0.59	1.41	0.157	NS
Total	2.79 ± 1.05	2.53 ± 0.70	1.22	0.225	NS

of MAIS score range (31–35) for children ≤ 3 years (53.3% = 8 children); was higher than that for > 3 years (0%). Those differences were; statistically highly significant (Table 5).

There was an inverse correlation between; age at CI, and CAPS, MAIS scores. While; there was direct correlation between MAIS & CAPS (Table 6).

There was a Signiant difference as regards acquiring first word and sentences between both groups (Table 7).

The difference between both groups was non-significant as regarding the receptive, expressive, and total language age (Table 8).

There was a significant correlation between CAPs Score and language age, as when the CAP score increase, language age also increased (Table 9).

There was a significant correlation between MAIS Score and language age, as when the MAIS score increase, language age also increased (Table 10).

Table 9 Correlation between CAP scores and total language age in both groups

	Total language age ***Mean ± SD***	**CAPS scores** ***Mean ± SD***	**Correlation coefficient "r"**	***P* value**	**Significance**
Groups A (CI ≤ 3 years)	2.79 ± 1.05	4.7 ± 0.6	0.740	0.00	Significant
Groups B (CI > 3 years)	2.53 ± 0.70	2.8 ± 0.7	0.821	0.00	Significant

Discussion

CI is considered as a powerful tool for children with severe to profound SNHL in their ability to hear and acquire age-appropriate communication skills. Scientists agreed that variability in speech and language outcomes is the most challenging and important unresolved problem [6].

CI operations at our institute show a high success rate. As a result of continuous increase of the numbers of CI patients and the need for improving our results especially in the area of the language acquisition; we had to search for evidence-based factors which can directly improve the verbal outcomes of CI patients especially in prelingual children.

We had to study the effect of the age of implantation, and the early receiving "as much as normal" auditory stimuli which should stimulate and improve the language acquisition. Identifying the points of weakness to implement in the rehabilitation program to improve CI language skills and quality of life. Also to predict their language outcomes and reach a reasonable counseling to parents for early intervention.

We monitored the auditory perception development after CI in children being 3 years old or younger or, older than 3 years old, after 18 months of their CI operation. From the collected data, the number of females for age > 3 years were 12 with a percentage of 75%, which was higher than that for age ≤ 3 years which was 5 females (33.3%). While, the number of males for age ≤ 3 years was 10 (with a percentage, 66.7%) that was higher than that for age > 3 years (25%). These differences; were statistically significant. As there is cultural significant difference regarding care for male children health and awareness especially at the rural areas in comparison to the that for female children.

The mean CAPS & MAIS scores for children CI ≤ 3 years, were higher than those for > 3 years. These differences were, statistically highly significant, as their score was significantly higher than children with older age for CI; which approving that the earlier the age of implant, the better auditory perception would be developed. This could be explained by the higher brain plasticity at the younger age group, also the environmental stimulation and early exposure to auditory stimuli in a golden period of age for language acquisition.

Regarding CAPS score, children CI age > 3 years had the score [3] with higher percentage than those ≤ 3 years old, while children with CI age ≤ 3 years had the higher CAPS score [5] than the children > 3 years old CI. The same results were found for the MAIS scores, with direct correlation between MAIS & CAPS score, as when CAPS score is high the MAIS score also is high, and vice versa.

"When is the optimal time to provide a young congenitally deaf child with a cochlear implant (CI)?" is a common question with varied answers. Neuroscientific research answers the question about sensitive periods, the central auditory pathways deterioration, plasticity in the maturing brain, and cortical re-organization especially when stimulation patterns differ from the norm.

Sensitive period for the development of the central auditory system is a time during which the central auditory pathways are maximally plastic and primed for stimulation-driven development. Therefore, it is reasonable to believe in doing cochlear implantation within the sensitive period would achieve maximum benefits and results [7].

Table 10 Correlation between MAIS scores and total language age in both groups

	Total language age ***Mean ± SD***	**MAIS scores** ***Mean ± SD***	**Correlation coefficient "r"**	***P* value**	**Significance**
Groups A (CI ≤ 3 years)	2.79 ± 1.05	33.4 ± 3.3	0.939	0.00	Significant
Groups B (CI > 3 years)	2.53 ± 0.70	18.9 ± 3.3	0.872	0.00	Significant

Children who received a cochlear implant before the age of 5 years show greater benefit in their speech production skills, speech intelligibility, and less sound errors than children with older age, [8].

There is great individual variability among linguistic skills in CI implanted children, which can be affected by many variables, such as intellectual abilities, age of diagnosis of the hearing loss, time of beginning language rehabilitation, how is the plasticity of the child's brain, and basic cognitive competence is crucial for learning. These factors have significant differences between the different studies. In this study although children who implanted before the age of 3 years have a significant higher auditory skills and perception, also acquired their first word and first sentence earlier than children who were implanted after the age of 3 years, but there were no significant differences as regard receptive, expressive, total language ages. This is in agreement with [9], who showed that linguistic progress and language development did not differ between children who received their cochlear implants in the first year compared to children who received their CI in the second year.

[10], found that, early implanted children have better auditory abilities with agreement to our results, but regarding speech production and intelligibility they developed better than the older implanted children. Same as [11], who found that children who received CI at earlier age have better skills on speech and language perception, with a better linguistic skill than children received CI later.

[12], found no difference in the long-term language performance of children implanted before age of 3 years and those implanted between 3 and 6 years of age.

There is a limited studies for children with the young age; less than 3 years, so we studied this age group. More limited studies are available for another youngest group (less than 1 year old) because of risk of complications for CI operation with this age as thin skin, thin skull, not totally developed mastoid process making the surgeon and the parents more suspicious for the results and taking the risk [13]. Having a question that needs also a clear answer how to get benefits from this plasticity and neurophysiological factors with respect to the risk factors.

Conclusion

The auditory perception development after CI in children being 3 years old or younger is much better than the older children which would be reflected on their speech perception and acquiring their 1st word and sentence, but language development did not differ between both groups for this period of follow up. With a need of further detailed full language aspects assessment and follow up to ensure these results.

Abbreviations

CI Cochlear implant
CAP Categories of auditory performance
MAIS Meaningful auditory integration scale

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Author's contributions
Applying questioners and language assessment, data collection, writing manuscript, analysis of the data was done by Dr Nihal Hisham. Audiological evaluation of the outcome of the CI was done by Dr Hanaa Fadel.

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Availability of data and materials
The datasets used and analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate
Ethical approval was obtained for the current study from the ethics and research committee of the National hearing and speech institute, Egypt, and the parents of the patients signed a fully written informed consent before enrolment in the study.

Consent for publication
Not applicable.

Competing interests
The authors declare that they have no competing interests or conflicts of interest.

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References

1. Hegazi M, Dina E, Abdelhamid N (2018) Md thesis, phonological awareness in specific language impairment, attention deficit hyperactive disorder, and cochlear implants users Faculty of Medicine, Ain Shams University, Cairo, Egypt
2. Vishal G, Sharma S, Singh S (2020) Effects of age at cochlear implantation on auditory outcomes in cochlear implant recipient children Indian. J Otolaryngol Head Neck Surg 72(1):79–85
3. Johanna N, Geers E (2007) Will They catch up? The role of age at cochlear implantation in the spoken language development of children with severe-profound hearing loss. J Speech Lang Hear Res 50(4):1048–1062
4. Abou HA, Elsady S, Elshobary A, Gamal EN, Ibrahiem A, Owes A (2011) standardization, translation and modification of the preschool language scale – 4 (a doctoral dissertation), faculty of medicine. Ain Shams University, Cairo, Egypt
5. Archbold S, Lutman M, Marshal D (1995) Category of auditory performance. Ann Otol Rhinol Laryngol 166(1):312–314
6. Caldwell A, Nittrouer S (2013) The emergence and development of a strong and changing partnership. Gesture and speech 8:22–44
7. Sharma A, Nash AA, Dorman M (2009) Cortical development, plasticity and re-organization in children with cochlear implants. J Commun Disord 42(4):272–279
8. Tye-Murray N, Spencer L, Woodworth G (1995) Acquisition of speech by children who have prolonged cochlear implant experience. J Speech Hear Res 38(2):327–37
9. Szagun G, Stumper B (2012) Age of experience? The influence of age at implantation, social and linguistic environment on language development in children with cochlear implants. J Speech Lang Heaing Res 55:1640–1654

10. Bassiouny S, Hegazi M, Saber A, Shoeib R, Hassan S (2006) The effect of age at implantation on the language and speech of cochlear implanted children: A 3-year follow up. Ain Shams Med J 57(10):1307–1321
11. Tomblin J, Barker Brittan A, Spencer l, Zhang X, Gantz J, (2005) The effect of age at cochlear implant. Initial stimulation on expressive language growth in infants and toddlers. J Speech, Lang Hearing Res 48(5):1243
12. Van H, Deriaz M, Patrucco-Nanchen T, Kos M (2010) performances in prelingual implanted children according to the age of implantation and the duration of CI use. Cochlear Implants Int 11(1):268–271
13. Holt R, Svirsky M (2008) An exploratory look at pediatric cochlear implantation: is earliest always best? Ear Hear 29(4):492–511

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