

# Variables affecting speech intelligibility in prelingual Arabic speaking cochlear-implanted children

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## Background

Speech intelligibility (SI) is usually expressed as the degree to which a speaker's intended message can be recovered by other listeners. It is determined by many factors that may be affected by the degree of hearing loss. The use of cochlear implants (CIs) can facilitate the development of speech and language skills of prelingually deaf children. Thus, improvements in SI after CI fitting can provide indirect evidence of sensory aid benefits.

## Aim

This cross-sectional study aimed to explore the different variables that affect SI in prelingual CI children in order to achieve the maximum benefit for improving SI in such candidates.

## Participants and methods

This study included 30 prelingually hearing-impaired participants, with ages ranging from 6 to 10 years. They used bilateral hearing aids for a duration of  $2.6 \pm 1.7$  years before undergoing CI, which was performed at ages ranging from 4 to 9 years. They were enrolled in specific language intervention programs after implantation for a duration ranging from 1 to 3.8 years. Then, the Arabic Speech Intelligibility test was used to assess their SI. The effect of different variables on their SI was assessed through both comparative and correlative analysis.

## Results

SI scores showed highly significant differences in patients at younger age at implantation (aged  $\leq 5$  years) and in those who had received language therapy for more than 2 years after implantation. Meanwhile, preimplantation therapy for more than 1 year and usage of hearing aids for more than 1 year before CI had significant effects on the SI scores. SI was highly significantly negatively correlated with age at CI and highly significantly positively correlated with the duration of postimplantation therapy. The SI scores were also affected by the three groups of the SI test. The front consonants had higher significant scores compared with both back consonants and sentences, and back consonants had significantly higher scores compared with sentences.

## Conclusion

The SI of prelingual cochlear-implanted children was affected by all of the studied variants. However, for best SI, age at implantation and postimplantation therapy duration should be considered to enable better SI in these children.

## Keywords:

Arabic test, cochlear implants, hearing impairments, speech intelligibility

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## Introduction

'Speech intelligibility' (SI) refers to the degree to which a speaker's intended message can be recovered by other listeners [1], or the comprehensibility of the specific linguistic information encoded by a speaker's utterances [2].

Measuring SI is, however, problematic in patients with hearing impairment because it is affected by a number of factors including the experience of the listener, the context in which the sentence was spoken, the visibility of the speaker, the familiarity of the speaker with the material spoken, and the articulation/phonological aspects, suprasegmental factors, contextual and semantic/morphologic/syntactic features, and voice

quality [3]. The extent to which these parameters are affected depends on the degree of hearing loss; the worse the hearing, the more these parameters are affected.

Hearing loss affects a large range of consonants including stridents, velars, nasals, and glides. The error types are mostly substitutions, distortions, and omissions of word initials that mostly affect SI. Poor pitch control or excessive pitch variation may also contribute to reduced SI [4]. Many studies considered listener's experience to be the best known factor that can influence the intelligibility of speech [5]. Studies completed during the 1960s–1980s revealed that the speech of children with severe to profound hearing losses was ~20% intelligible on average [6].

Cochlear implants (CIs) have been proven to provide an access to the speech signal in profoundly deaf children who derive no benefit from hearing aids (HAs). CIs do not restore normal hearing, but are individually programmed to provide the recipient with hearing sensitivity within the speech range [7]. A substantial number of studies have demonstrated that the use of CIs can facilitate the development of speech and language skills in children who are prelingually deaf.

The extent of SI is likely to be an indicator of the auditory perceptual benefits received from sensory aids in young sensory aid recipients [8]. Thus, improvements in intelligibility after CI fitting can provide indirect evidence of sensory aid benefit. In contrast, a lack of improvement in SI might indicate that children are not receiving full benefit from their sensory aids. In the population of prelingually deaf CI recipients, the frequently considered factors to individual variability include age at implantation, duration of CI use, and communication mode [9].

Intelligibility scores can provide important supplemental information for decisions regarding the adjustment or replacement of sensory aids [10]. To our knowledge, no previous study has been conducted to assess intelligibility scales of speech of Arabic speaker prelingual CI children until now. Therefore, the aim of this study was to explore the different variables that might affect the intelligibility of speech in prelingual CI candidates to achieve the maximum benefit for SI.

## Participants and methods

The current study was conducted on 30 prelingual children, 13 (43.3%) boys and 17 (56.7%) girls, with an age range of 6–10 years and a mean age of  $7.9 \pm 1.3$  years at the time of performing the study. The participants were born deaf or had lost their hearing in the first 2 years of life. Their severe to profound sensorineural hearing loss was confirmed by age-matched hearing evaluation. All candidates were recruited from Ain Shams University hospitals from March 2011 to August 2013 after obtaining consent from their parents. All candidates were of average mentality according to the Stanford-Binet Intelligence Scale test [11]. Their total language age was 3 years or more and they were capable of speaking a mean of at least three-word-length sentences as assessed by the Arabic language test [12]. Patients with visual impairments or brain damage were excluded.

All participants were fitted with bilateral HAs before performing the CI with a mean duration of  $2.6 \pm 1.7$  years and had been receiving preimplantation language therapy for a mean duration of  $2 \pm 1.6$  years.

All children were unilaterally implanted either with Medel Sonata or Cochlear Freedom CI system. Their ages at implantation ranged from 4 to 9 years, with a mean of  $6.2 \pm 1.5$  years. They had been receiving regular language sessions after implantation twice weekly at the Phoniatric Unit, Ain Shams University hospitals, for a duration ranging from 1 to 3.8 years, with a mean of  $2.2 \pm 1$  years.

The participants were divided into four subgroups on the basis of the following variable parameters:

- (1) Age at implantation (A): this was further divided into two subgroups, subgroup A1 ( $\leq 5$  years) and subgroup A2 ( $> 5$  years).
- (2) The duration of preimplantation language therapy (B): this was further divided into two subgroups, subgroup B1 ( $\leq 1$  year) and subgroup B2 ( $> 1$  year).
- (3) The duration of wearing the HA before implantation (C): this was further divided into two subgroups, subgroup C1 ( $\leq 1$  year) and subgroup C2 ( $> 1$  year).
- (4) The duration of postimplantation language therapy after implant (D): this was further divided into two subgroups, subgroup D1 ( $\leq 2$  years) and subgroup D2 ( $> 2$  years).

All candidates were evaluated according to Ain Shams Phoniatric Unit's protocol for language assessment [13]. Aided response was evaluated in all children using CIs in free field to ensure within-normal aided response. Children with unsatisfactory aided response were excluded from this study.

All participants were subjected to the Arabic Speech Intelligibility test [14]. The test is designed to provide an estimation of the overall SI. It provides the examiner with a final score in percentage, which is meant to be an objective measure of a child's SI. It is composed of three picture sets (front consonant monosyllabic words, back consonant monosyllabic words, each consisting of 20 cards, and 10 cards of action verb sentences). The child is asked to name the pictures (which the listeners cannot see) correctly enough that the listener can identify which word among the cards the child is trying to say. The score may denote unintelligible speech (0–29%), poorly intelligible speech (30–50%), fairly intelligible speech (51–66%), good intelligible speech (67–84%), and excellent intelligibility (85–100%).

## Statistical analyses

The collected data were revised, coded, tabulated, and introduced into a PC using statistical package for social science (SPSS 15.0 for windows; SPSS Inc., Chicago, Illinois, USA). Data were presented and suitable analysis was carried out according to the type

of data obtained for each parameter. The numerical data were presented as means, ± SD, and minimum and maximum values (range).

The non-numerical data were presented as frequency and percentage. The independent-samples *t*-test was used to assess the statistical significance of the difference between two study group means, whereas one-way analysis of variance was used to assess the statistical significance of the difference between more than two study group means. Once we had determined that differences existed among the means, one-way analysis of variance, post-hoc tests, and pairwise multiple comparisons were applied to determine which means differed. Range tests were used to identify homogenous subsets of means that were not different from each other. Pairwise multiple comparisons were used to test the difference between each pair of means, which yielded a matrix in which asterisks indicated significantly different group means at an  $\alpha$  level of 0.05. Pearson Correlations were used to assess the strength of association between two quantitative variables. The correlation coefficient denoted symbolically as '*r*' defines the strength and direction of the linear relationship between two variables. *P* values less than or equal to 0.05 were considered significant.

**Results**

All 30 prelingual participants in this study showed a mean total score of their final SI test of 60 ± 26%, with a range of 22–96%. Words showed a higher SI score of 48 ± 20% (range 12–76%) compared with sentences, which had an SI of 12 ± 6% (range 2–22%). Front consonants had an SI score of 30 ± 11% (range 10–42%), whereas back consonants had an SI score of 18 ± 11% (range 2–36%).

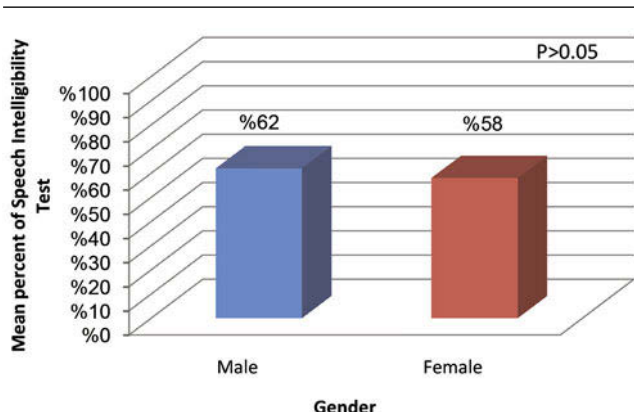
There was no statistically significant difference between the two sexes with respect to the mean scores of the SI test ( $P > 0.5$ ), as shown by the independent-samples *t*-test (Table 1 and Fig. 1). Different variants including the age at CI, duration of therapy, duration of fitting the HAs before the CI, and duration of therapy after the CI were all compared with respect to the SI scores. (Table 2). The independent-samples *t*-test revealed that there were highly statistically significant differences between SI and age at CI and duration of postimplant therapy ( $P \leq 0.001$ ). Meanwhile, each of the two subgroups, duration of preimplant therapy (>1 year) and preimplant HA fitting (>1 year), were associated with higher significant SI ( $P \leq 0.05$ ).

Analysis of the correlation between SI and the different variables revealed a highly significant negative correlation between SI and the age at CI ( $r = -0.9$ ;  $P \leq 0.001$ ). Significant positive correlations were detected between SI and duration of preimplant HA and preimplant therapy ( $r = 0.39$  and  $0.42$ , respectively;  $P \leq 0.05$ ). Meanwhile, the duration of postimplant language therapy correlated positively and highly significantly with the SI score ( $r = 0.89$ ;  $P \leq 0.001$ ) (Table 3).

There was a highly statistically significant difference between the mean scores of the three subgroups of SI for all groups – namely, the front consonant words, back consonant words, and sentences. The most significance denoting high intelligibility was for the front consonant words followed by the back consonant words, and the least was for sentences (Table 4 and Fig. 2).

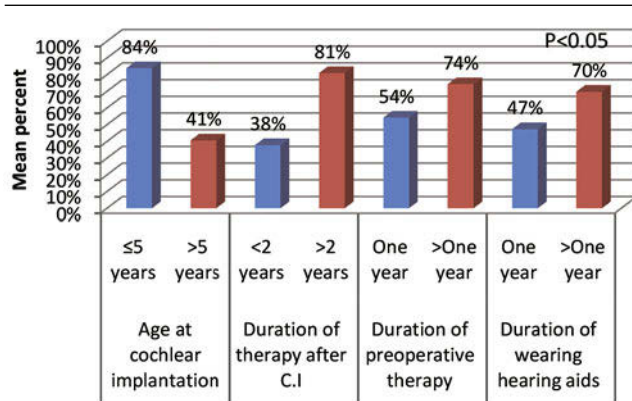
The mean percentage differences in SI for back consonants versus front consonants, for sentences versus front consonants, and for sentences versus back

Figure 1



Comparison between sexes regarding speech intelligibility.

Figure 2



Comparison between the speech intelligibility scores of the front consonant words, back consonant words, and sentences.

**Table 1 Comparison between sexes regarding the speech intelligibility scores**

Arabic speech intelligibility test %	N	Mean (%)	SD	t	P value	Significance
Male	13	62	27	0.43	0.5	NS
Female	17	58	26			

*P* > 0.05: NS; *P* ≤ 0.05: significant (S); *P* ≤ 0.001: highly significant (HS).

**Table 2 Comparison of speech intelligibility scores between the different subgroups**

Arabic speech intelligibility test %	N	Mean (%)	SD	t	P value	Significance
Age at cochlear implantation (years)						
≤5	15	83.8	11.7	8.94	0.000	HS
>5	15	40.6	14.6			
Duration of preimplant therapy (years)						
1	18	54.2	25.2	-2.24	0.03	S
>1	12	74.2	21.7			
Duration of postimplant therapy (years)						
<2	13	37.7	13.5	-8.68	0.000	HS
>2	17	80.9	13.5			
Duration of wearing hearing aids (years)						
1	10	47.3	22.8	-2.45	0.02	S
>1	20	69.7	24.0			

*P* > 0.05: NS; *P* ≤ 0.05: significant (S); *P* ≤ 0.001: highly significant (HS).

**Table 3 Correlation between speech intelligibility scores and the different variables**

Variables	Speech intelligibility
Age at CI (years)	
<i>r</i>	-0.90
<i>P</i> value	0.000
Significance	HS
Duration of preimplant therapy (years)	
<i>r</i>	0.39
<i>P</i> value	0.03
Significance	S
Duration of postimplant therapy (years)	
<i>r</i>	0.89
<i>P</i> value	0.000
Significance	HS
Duration of wearing HA (years)	
<i>r</i>	0.42
<i>P</i> value	0.02
Significance	S

CI, cochlear implant, HA, hearing aid; *P* ≤ 0.05: significant (S); *P* ≤ 0.001: highly significant (HS).

**Table 4 Comparison between front consonant words, back consonant words and sentences regarding speech intelligibility**

Speech intelligibility	Mean ± SD (%)	F	P value	Significance
Front consonant words	30 ± 11	26.44	0.000	HS
Back consonant words	18 ± 11			
Sentences	12 ± 6			

*P* > 0.05: NS; *P* ≤ 0.05: significant (S); *P* ≤ 0.001: highly significant (HS)

consonants were statistically highly significant. Using back consonant words rather than front consonant words reduced the mean percentage difference in SI by -11%, whereas using sentences rather than front and back consonant words reduced the mean percentage difference in SI by -18 and -6%, respectively (Table 5 and Fig. 3).

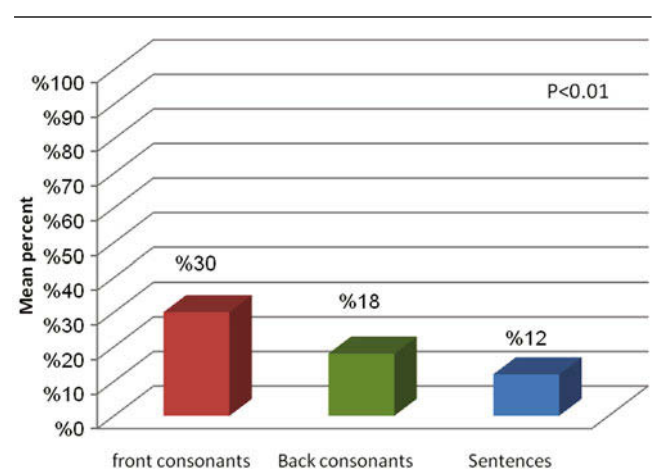
### Discussion

Readily intelligible connected speech is the ultimate goal of speech intervention for children with hearing loss. It seems reasonable then that children’s progress toward this important goal would be monitored closely [15]. Integration into mainstream elementary classrooms is one of the key motivations for CI use in very young children. Successful integration requires the development of many social, communicative, preacademic, and academic skills before regular school placement [16]. SI of prelingual CI children might affect this challenge.

This study showed that the overall mean SI score of all participants after regular postimplantation therapy with a mean duration of 2.2 ± 1 years was 60 ± 26%. This is nearly commensurate with the findings of Chin et al. [17], in whose study participants received their implants at a relatively young age (M = 38 months) and achieved a mean intelligibility score of 34.5% after an average of 28 months of CI use.

The statistically significant differences detected in this study on comparing SI scores in relation to the different variants including age at implantation of CI, duration of preimplantation therapy, and duration of wearing HAs before CI and duration of postimplantation

**Figure 3**



Comparison of the speech intelligibility scores between the different subgroups.

**Table 5 Post-hoc multiple comparisons to detect the least significant differences between front consonant words, back consonant words, and sentences**

(I) Speech intelligibility	(J) Speech intelligibility	Mean difference% (I-J)	P value	Significance
Back consonant words	Front consonant words	-11	0.000	HS
Sentences	Front consonant words	-18	0.000	HS
	Back consonant words	-6	0.01	S

$P > 0.05$ : NS;  $P \leq 0.05$ : significant (S);  $P \leq 0.001$ : highly significant (HS) by post-hoc tests.

therapy emphasize the positive role of the CI and its marked impact on the linguistic competence of profoundly hearing-impaired children. Our finding was comparable to that of Shu-Chen *et al.* [18], who showed that CIs before age 5 years resulted in greater improvement in speech production skills compared with CIs after that age, which could be related to neural plasticity. It was also reported by Sharma and Dorman [19] that when children are implanted early in childhood the central auditory development becomes age appropriate within 3–6 months after implantation and continues to be normal throughout their childhood years. Decline in neural plasticity with age was also proven by Zwolan *et al.* [20], who focused on the inability of adults to form necessary neural structures required to process language and speech.

Moreover, the age at implantation and duration of postimplant therapy showed highly significant negative and positive correlative values, respectively, in our analysis of the variable affecting the SI of the prelingual CI children in this study.

Our results were comparable to that of Fryauf-Bertschy *et al.* [21], who suggested that young children represent the best candidates for a CI. Delayed implantation after the early onset of deafness predicts lower levels of speech reception. Moreover, Kirk *et al.* [22] reported that children with congenital deafness who were younger than 4 years and received CIs developed significantly better speech and language skills compared with children who received implants after 6–7 years of age. Therefore, the age of the child at the time of implantation is critical for SI progress, as the age of 4 years is the age at which a normal developing child's spontaneous speech should be intelligible to unfamiliar adults, even though some articulation and phonological differences are likely to be present [23]. Choosing a higher age limit (5 years) for subgrouping of our studied children, compared with other studies [24,25], could be explained by the availability and cost of CI in a developing country compared with developed countries.

Preimplantation therapy duration is also an important factor that had an effect on SI. Our results revealed that children who underwent therapy for 1 year or more before implantation achieved a statistically

significantly higher percentage of SI compared with those who attended therapy for less than 1 year. This analysis is unique to our study and therefore should be validated in a larger group of children.

It was recently speculated that central auditory processing modifications might begin with the onset of hearing loss. It has been shown in a functional MRI study of a cohort of 10 postlinguistically deaf individuals that specific brain reorganizations associated with phonological processing in the right posterior superior temporal gyrus/supramarginal gyrus were influenced by the duration of severe to profound HL [26] as well as the duration of HA use [27]. Accordingly, early binaural amplification (aided by speech therapy) is suggested to result in slowing down of the related central reorganization that is the likely cause of the decreased performance. This was proven in the current study, as children who wore HAs for 1 year or more before CI had higher intelligible speech compared with those who wore HAs for less than 1 year.

Whitehill [28] described intelligibility of speech as the most important measure of any speech disorder, and improving it should be the primary goal of therapeutic intervention. Post-CI therapy is the last variable evaluated to determine its effect on SI. The results of the current study proved that, longer the duration of postimplantation therapy (>1 year), better the SI outcomes, which has been attributed to be due to both time factor and intervention strategy. This finding is supported by many studies including that of Tobey *et al.* [8], who reported that speech production in children with CI is influenced by implant characteristics, including the length of time, using the newest speech processing strategies, as well as the educational programs emphasizing oral–aural communication.

Use of front consonant words was proven in the current study to be the most intelligible in the CI children's speech, followed by back consonant words, and the least intelligible were sentences. These findings give extremely important information that must be considered in clinical applications. They agree with the results of Lach *et al.* [29], who declared that young hearing-impaired children produce front consonants more often than they do back consonants and they

use front consonants with greater frequency than do normally hearing children. They often produce more visible consonants (i.e. labials vs. coronals or dorsals) [30]. Further, phonemes produced at the front of the mouth are more often produced correctly than phonemes produced at the back of the mouth. This makes sense when one considers that the relative visibility of articulators should be important to hearing-impaired children [31]. This general trend of better production of phonemes has been found not only for production of isolated words and sentences but also for spontaneous speech [32].

McGarr [33] has shown that intelligibility scores for hearing-impaired speakers may vary considerably depending on speech material (sentences or words). As the SI of the speech material (sentences or words) is influenced by the length of the utterance, presence or absence of familiar vocabulary, and the presence of less complex syntax [5], it is expected to find words more intelligible than sentences, as proven in the current study.

Correlation analyses were conducted in this study to investigate separately the effect of each variable on the SI, apart from the remaining studied variants. These revealed that age at implantation was highly significantly negatively correlated SI. The duration of postimplantation language therapy was highly significantly positively correlated to SI ( $P < 0.001$ ) compared with the duration of preimplantation therapy and HA usage, which were significantly positively correlated to the SI ( $P < 0.05$ ). On the basis of these findings we concluded that, although these two variants – duration of preimplantation therapy and HA – have significant effect on the SI, they should not negatively interfere or delay the age at CI and consequently miss out the more effective factors: CI at earlier age and the following postimplantation therapy.

Factors that were thought to be major contributors to SI – such as duration of wearing HAs and duration of preimplantation therapy – did not have the highly significant effect on SI as the other two variants – age at CI and duration of postimplantation therapy – and therefore these last two variants should be given greater priority while considering prelingual implantation of the cochlea. It is not only early fitting of HA but also early CI that has been hypothesized to affect central auditory development – a benefit that should not be missed in our vision for best SI in prelingual CI children.

We recommend not only a longer follow-up comparative study of SI in prelingual cochlear-implanted Egyptian children but also one that is multicentric in order to

compare the effect of the different types of CIs on SI in this category of children.

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## Acknowledgements

### Conflicts of interest

None declared.

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