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# Outcome of language therapy in bimodal-fit children versus unilateral cochlear implant children in bilateral sensorineural hearing impairment: a case-control study

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## Abstract

**Background:** Treating hearing-impaired children aims not only to improve their hearing but also to enhance language acquisition capability. In our community, the CI usually performed on one side because of financial issues at least for a period of time. Consequently, the brain may neglect the unfitted ear. Contralateral hearing aid is an alternative solution when bilateral CI is unavailable. Our purpose is to evaluate the language outcome in bimodal-fit children who using cochlear implant (CI) and contralateral hearing aid (HA) compared to children using unilateral cochlear implant only.

**Results:** In this case-control study, 15 children who are using binaural-bimodal stimulation by unilateral CI and contralateral HA and 15 children using monaural cochlear implant received auditory training and language therapy. All participants have been assigned randomly from the Phoniatics and Audiology clinics. Filtering of patients was made to get the two groups matched regarding age, sex, family motivation, age of implantation, and age of hearing impairment. Evaluation and language therapy were performed in the Phoniatics clinic. Language progress in each group was compared over different time-points. Also, it was compared between the two groups in each time-point. Both groups revealed significant language improvement over time with intensive auditory training and language therapy. In addition, the bimodal-fit children showed better language and speech outcomes than the unilateral CI children in receptive semantics, expressive semantics, word class, mean length of utterance, and speech intelligibility. The differences were significant with *P*-values 0.047, 0.034, 0.03, 0.016, and 0.028, respectively, after 9 months of rehabilitation.

**Conclusion:** Bimodal-fit children showed better improvement in language than the unilateral CI group. The contralateral hearing aid may be complementary to the unilateral cochlear implant by covering wider speech frequency range. Also, it prevents auditory deprivation and enables binaural hearing with positive impact on language outcome.

**Keywords:** Unilateral cochlear implantation, Bimodal fit, Language therapy, Language outcomes

## Background

Bilateral cochlear implantation is considered the most recent method for binaural stimulation in bilateral severe-to-profound sensorineural hearing loss in many countries. However, in others, bilateral cochlear implantation may not be available due to the limited financial support and low socioeconomic statuses of citizens. The

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bimodal fitting (monaural cochlear implant and hearing aid fitting in the contralateral ear) is an alternative way for binaural stimulation in children with residual hearing in the non-implanted ear [1, 2]. Recent studies of deafness in children showed evidence of an “aural preference syndrome” in which single-sided deafness in early childhood reorganizes the developing auditory pathways toward the hearing ear, with weaker central representation of the deaf ear. Delayed therapy consequently compromises benefit for the deaf ear, with slow rates of improvement over time. Therefore, asymmetric hearing needs early identification and intervention. Early effective stimulation in both ears through appropriate fitting of auditory devices within the sensitive period of development has a cardinal role for securing the function of the impaired ear and for restoring binaural/spatial hearing [3, 4]. A child with hearing loss is facing certain problems arising from deficits in spoken language abilities. Deficient language commonly leads to reading problems and limits academic performance. Children with severe-to-profound hearing loss treated by cochlear implant can understand and produce spoken language better than those treated by hearing aids [5]. Children with untreated unilateral hearing loss experience deficits in speech perception and language learning [6–8]. So, it is likely that binaural hearing is essential for speech perception and language learning. The evidence demonstrated that binaural benefits for sound localization and speech perception can be obtained by many individuals using either bimodal stimulation or bilateral implantation [9]. The bimodal stimulation can improve sound localization and speech recognition in both quiet and noisy environments as reported in extensive researches [10–13]. Many studies had investigated the benefits of binaural stimulation as regard auditory processing. However, there is lacking in researches investigating the language development and outcomes following bimodal stimulation in children.

The binaural hearing promotes nearly normal auditory cortical organization. This facilitates auditory skills development in early childhood and avoids the risk of auditory deprivation with positive impact on language perception and acquisition [3, 4]. Learning language involves more than just recognizing words, whether in noise or in quiet and whether in isolation or in sentences. A child can learn the native language without any previous knowledge or expectations about the syntactic structure or grammar of that language. Children must discover how the language they have to learn is structured at all levels. For example, a child must understand and produce simple and complex sentences, verb tense, plurals, pronouns, question, etc., which is important in his/her native language. Learning about these linguistic features generally happens within the first 3 years of life. The aim of the current

research is to evaluate the efficacy of auditory training and language rehabilitation in bimodal fitting compared with unilateral cochlear implant children regarding language perception and production in an effective communication. Receptive and expressive language abilities, syntactic structure of sentences, and speech intelligibility will be addressed. This is in order to determine the impact of binaural-bimodal stimulation and unilateral CI on the language acquisition and development.

## Methods

### Participants

This study was conducted in the Sohag University Hospital after approval of the Institutional Ethical Committee. Written informed consents were obtained from all parents for having their children participate in this research work. This study included 30 participants with bilateral severe-to-profound sensorineural hearing impairment (HI) who did not use any form of sign language. The majority of subjects had symmetrical hearing impairment (severe to profound or profound). Few subjects in the bimodal group ( $n = 4$ ) had asymmetrical hearing impairment (severe to profound and profound HI). The participants have been recruited from the Phoniatics outpatient clinic. In this case-control study, all participants were matched regarding age, sex, IQ category, family motivation, age of implantation, and time of hearing impairment in relation to first language learning.

The inclusion criteria included the following:

- a) Severe-to-profound peripheral sensorineural hearing loss
- b) Aided-hearing threshold should not be more than 65 dB for HA use in group A.
- c) Nonverbal IQ above 80
- d) Age at CI is not more than 6 years.
- e) Parents with typical hearing who reported speaking only Arabic to their children
- f) Motivated families to work with their children at home

Children with any major health condition other than hearing impairment that could delay language, cognitive, or motor development were excluded from the study.

All participants were treated by cochlear implantation (CI) in one ear. Parents of all participants were instructed to use HA in the contralateral ear after explaining its potential benefit. Fifteen children followed the instructions and received hearing aid in the contralateral ear. However, there are other 15 families did not follow the instructions and refused to use HA anymore; hence, their children remained with unilateral CI only. In the current research, there are 2 groups, each composed of 15

subjects: the subject group or group A (binaural-bimodal stimulation) and the control group or group B (monaural CI). There was no bias at all in assigning participants to either group. The only factor which determines groups is the willingness of parents whether to use contralateral HA for their children or not.

### Procedures

The participant's information was listed in Table 1. All participants were implanted with the MED-EL Sonata in the Otolaryngology Department, Sohag University Hospital. The IQ was measured for all children by non-verbal section of the Stanford-Binet 5 Arabic version (SB5-AR) [14]. Family motivation was based on 3 items according to history taking: (a) regular attendance to the language therapy sessions before implantation, (b) real family expectancy that CI operation itself will not get their child to speak without language therapy, and (c) willingness of the family to have their child speak. Family counseling given aimed mainly at improving language stimulation environment at home and stress on attending language therapy sessions for at least 2 years after implantation. The language-stimulating environment can be measured by the average number of hours the parents interact verbally with their child at home. Assessment for speech reading ability was performed by asking the child to identify or repeat 10 common words and 10 common sentences spoken by the examiner. These words and sentences including their pictures were taken from unpublished Arabic speech reading test done in the Ain Shams University Hospital. All children received intensive course of auditory training and language therapy as part of their rehabilitation program in the Phoniatrics Unit, Sohag University Hospital. Every child received 4 therapy sessions per week; each is 60 min. The content of session

varies according to the language level of the child. Generally, therapy sessions included auditory training, self-talk, and parallel-talk commenting on actions made by the child or by therapist in front of the child. These actions were made using flash cards, toys, and structured speech situations with stress on semantic, syntax, and phonology as well as conversational or play therapy (auditory-verbal therapy). Families were given counseling to work with their children at home by commenting on everyday listening/speech situations and structured listening/speech situations. Family expectancy and motivation were assessed in the interview, and any misconception was fixed during family counseling. The stated goal set from therapy was enabling the children to learn spoken Arabic language. Language assessment was conducted pre-therapy and post-therapy at 3 time-points (3, 6, and 9 months). The language parameters assessed were receptive semantics, expressive semantics, mean length of utterance, word class, and speech intelligibility. The language outcomes were compared over time within each group and in each time-point between the two groups.

### Language assessment

1. *Receptive semantics (RS)*: recognition of pictures is a measure of how well children comprehend spoken language. Every child has to point to a specific picture from multiple options (6 pictures) in response to verbal stimuli. The pictures included 10 semantic groups (6 pictures for each). These groups included body parts, family members, surrounding furniture, cloths, foods, fruits, vegetables, animals, transportations, and colors. The pictures within each semantic group were structured to be 2 familiar pictures, 2 less familiar pictures, and 2 rare picture items. The RS

**Table 1** Participants' personal and treatment information

Item		Group A (binaural-bimodal)	Group B (monaural CI)
Total number	30	15	15
Age	Mean $\pm$ SD	4.512 $\pm$ 1.019	4.806 $\pm$ 1.289
Sex distribution		7 F, 8 M	9 F, 6 M
Age of onset of HI (months)	Ranges	Birth — 36	Birth — 36
	Mean $\pm$ SD	11.46 $\pm$ 10.7	12.46 $\pm$ 12.2
Time from onset of HI to unilateral HA fitting	Range (months)	5–24	3–36
	Mean $\pm$ SD	11.4 $\pm$ 5.9	9.5 $\pm$ 11.3
Time from onset of HI to bilateral HA fitting	Range (months)	5–30	3–39
	Mean $\pm$ SD	13.7 $\pm$ 6.8	12.8 $\pm$ 11.9
Time from onset of HI to CI	Range (months)	12–66	12–80
	Mean $\pm$ SD	37 $\pm$ 13.8	31 $\pm$ 19.6
Time from onset of HI to bimodal fitting	Range (months)	15–60	
	Mean $\pm$ SD	40.5 $\pm$ 16.5	

score was measured as the correct responses to the total picture items (60).

2. *Expressive semantics (ES)*: it is the total number of vocabs uttered by the child and estimated by summation of vocabs collected by the two methods:
  - a. Behavioral testing of ES: it is the ability of children to name given pictures in question. The examiner shows the child a picture and asks him/her directly about its name. The same semantic groups in RS were used. The ES score was measured as the correct responses to the total pictures (60). We usually started by ES; if the child names the item correctly, then he definitely knows it and no need for testing RS of that item. Items which were not named by the child were tested for RS.
  - b. Spoken words list: it is a list of words which the child usually utters in everyday life as listed by parents and not included in the ES.
3. *Word class score*: it represents the word class level which the child acquires in his/her vocabulary. The word class score (1–7) was proposed for this study as hierarchy of grammatical words acquired by children (Table 2). It was taken from the expressive syntax items of the *Preschool Language Scale* 4th edition Arabic version (PLS4-AR) [15]. The score is based on the same order of normal grammatical development in our community as in the standardized PLS4-AR.
4. *Mean length of utterance (MLU)*: this was evaluated by observing spontaneous speech of the child in the interview or a pre-recorded video at home, behavioral testing, and parent telling. Observing the child during play with his/her mother and by eliciting open-ended conversation with the child or watching a pre-recorded video provide rough measurement about the current linguistic ability. Then, behavioral testing was made by asking the child to describe 2 pictures; each contains multiple events which need formulating long and complex utterances. These pic-

tures were taken from SB5-AR test [14]. Evaluating the MLU by picture description was made by 3 Phoniatricians and matched with spontaneous speech observation. About 20–30 utterances were used for each child for calculating the MLU according to the child’s response. The MLU is equal to the number of morphemes (words) in the whole utterances divided by the number of utterances.

5. *Speech intelligibility*: The examiner elicited child’s speech during playing with toys. A sample of child’s speech was recorded during interview. Also, a pre-recorded audio or video made by parents at home was used. The speech samples were perceptually judged for intelligibility by 3 Phoniatricians. The percentage of incomprehensible speech in the sample is inversely related to the degree and score of speech intelligibility as shown in Table 3.

**Results**

All children were implanted before 2 years of life except 3 subjects (one in group A and 2 in group B) were implanted after 3 years. All verbal children have fair to good speech reading abilities with minimal insignificant differences among them. The mean IQ in group A and group B was  $92.8 \pm 7.6$  and  $93.2 \pm 6.4$ , respectively, with insignificant difference. The children were deprived from language stimulation environment at home before treatment. However, with family counseling, the number of

**Table 3** Speech intelligibility score

Score	Degree	% of incomprehensible speech
0	Severe unintelligibility	76–100%
1	Moderate unintelligibility	51–75%
2	Mild unintelligibility	25–50%
3	Fairly intelligible	Less than 25%

**Table 2** Word class

Word class score	Main grammatical words development
1	Mainly nouns and few verbs
2	Nouns and many verbs
3	Plus early pronouns questions and adjectives.
4	Master pronouns and questions, plus adjectives and possessives.
5	Plus regular plurals, past tense and quantity words.
6	Plus prepositions and negation in sentence, and master locatives.
7	Plus counting, colors, categorization, time indicators and irregular plurals.

hours of parent-child interaction by structured speech situation was increased from  $1.5 \pm 0.6$  to  $4.5 \pm 1.8$  in total participants with insignificant difference between the two groups. In the first 6 months, all sessions were individual. Type of therapy sessions was mainly individual. Group therapy started for those children who uttered 3-word sentence or more only in the last 3 months of the course. There were few drops out of sessions which were compensated in the same week. All the children included in the research completed the therapy course with good compliance of their families.

Comparison of language outcomes over time across different time-points was conducted using repeated measures one-way ANOVA in each group. In addition, the posttest (Tukey's multiple comparison) was used to show the biggest mean difference. These comparisons were made for receptive and expressive vocabulary and MLU.

1- Receptive semantic (RS): An analysis of variance showed that the receptive semantic was increasing over the 3 time-points of evaluation in group A with significant differences ( $P < 0.001$ ). Tukey's multiple comparison test showed significant differences in the all 6 comparisons among different time-points (pre- vs 3 months, pre- vs 6 months, pre- vs 9 months, 3 months vs 6 months, 3 months vs 9 months, and 6 months vs 9 months). The highest mean difference was 27.8 in pre-therapy versus 9 months comparison followed by 21.67 in pre-therapy versus 6 months comparison. Similarly, analysis of variance showed

that the receptive semantic was increasing over the 3 time-points of evaluation in group B with significant differences ( $P < 0.001$ ). The Tukey's multiple comparison test showed significant differences in all comparisons among different evaluation time-points with highest mean difference was 19.6 in (pre- versus 9 months) comparison followed by mean difference 11.47 in (pre- versus 6 months) comparison (Table 4).

2- Expressive semantic (ES): An analysis of variance showed that the expressive semantic in group A was increasing over the 3 time-points of evaluation with significant differences ( $P = 0.0056$ ). Tukey's multiple comparison test showed significant differences in the all 6 comparisons among different time-points with highest mean difference 68.4 between (pre- versus 9 months) comparison followed by 55.07 in the (3 months versus 9 months) comparison. Also, analysis of variance showed that expressive semantic was increasing over the 3 time-points of evaluation in group B with significant differences ( $P = 0.003$ ). Tukey's multiple comparison test showed significant differences in all comparisons except (pre- versus 3 months). The highest mean difference was 20.53 in (pre- versus 9 months) followed by 18.2 in (3 months versus 9 months) comparisons (Table 4).

3- Mean length of utterance (MLU): An analysis of variance showed that MLU in group A was increasing over the 3 time-point evaluations with significant difference ( $P < 0.001$ ). Tukey's multiple comparison test showed significant differences in all comparisons with biggest mean difference 2.4 in (pre-therapy ver-

**Table 4** Comparison of language parameters among different time-points within groups

Item	Group	Repeated measures one-way ANOVA		Multiple comparisons posttest		
		F	p-value	Posttest	Highest difference (pre- vs 9 ms)	p-value
Receptive semantics	A	(1.54–21.65) = 35.45	$P < 0.001$	Tukey	27.8	$P < 0.001$
	B	(1.44–20.14) = 32.48	$P < 0.001$	Tukey	19.6	$P < 0.001$
Expressive semantics	A	(1.032, 14.45) = 10.4	$P = 0.0056$	Tukey	68.4	$P = 0.004$
	B	(1.039–14.54) = 12.35	$P = 0.003$	Tukey	20.53	0.0114
Word class <sup>a</sup>	A		$P < 0.001$	Dunn	36.5 <sup>b</sup>	$P < 0.001$
	B		$P < 0.001$	Dunn	28 <sup>b</sup>	$P < 0.001$
Mean length of utterance	A	(2.36–33.11) = 45.36	$P < 0.001$	Tukey	2.4	$P < 0.001$
	B	(1.89–26.56) = 35.04	$P < 0.001$	Tukey	1.86	$P < 0.001$
Speech intelligibility <sup>a</sup>	A		$P < 0.001$	Dunn	34 <sup>b</sup>	$P < 0.001$
	B		$P < 0.001$	Dunn	29 <sup>b</sup>	$P < 0.001$

Table 4 shows comparison of the improvement over time in groups A and B by repeated measures one-way ANOVA and multiple comparisons posttest

<sup>a</sup> In these noncontinuous data, the nonparametric repeated measure one-way ANOVA (Friedman's test) was applied (no *F*-values). Dunn's test is the posttest for the nonparametric comparisons

<sup>b</sup> These values represent the highest rank sum differences (nonparametric). However, the rest of values in the column (parametric) represent the highest mean difference

sus 9 month) followed by 1.67 in (3 months versus 9 months) comparisons. Similarly, analysis of variance showed that MLU in group B was increasing over the 3 time-point evaluations with significant difference ( $P < 0.001$ ). Tukey's multiple comparison test showed significant differences in all except (3 months versus 6 months) comparisons with biggest mean difference 1.86 in (pre-therapy versus 9 month) followed by 1.46 in (3 months versus 9 months) comparisons (Table 4).

Although the data of word class and speech intelligibility were numeric, they were discrete (noncontinuous). So, the nonparametric repeated measures one-way ANOVA (Friedman test) was used for word class and speech intelligibility scores. In addition, the posttest (Dunn's multiple comparison) was used to show the highest rank sum difference.

1. Word class: it ranges from (0–1) in both groups pre-therapy. The word class ranged from (0–3) in 3-month and 6-month time-points and from (1–6) in the 9-month time-point in group A. In contrast, the word class in group B ranged from (0–1), (0–2), and (1–3) in the 3-month, 6-month, and 9-month time-points, respectively. Statistically, there were significant increases of word class score over time in both groups ( $P < 0.001$  for each). The Dunn's multiple comparison test for group A revealed significant differences in 3 comparisons: (pre- versus 6 months), (pre- versus 9 months), and (3 months versus 9 months). The highest rank sum difference was 36.5 for (pre- versus 9 months) in group A. In contrast, the Dunn's multiple comparison test for group B revealed significant differences in only one compari-

son (pre-therapy versus 9 months) with highest rank sum difference (28) (Table 4).

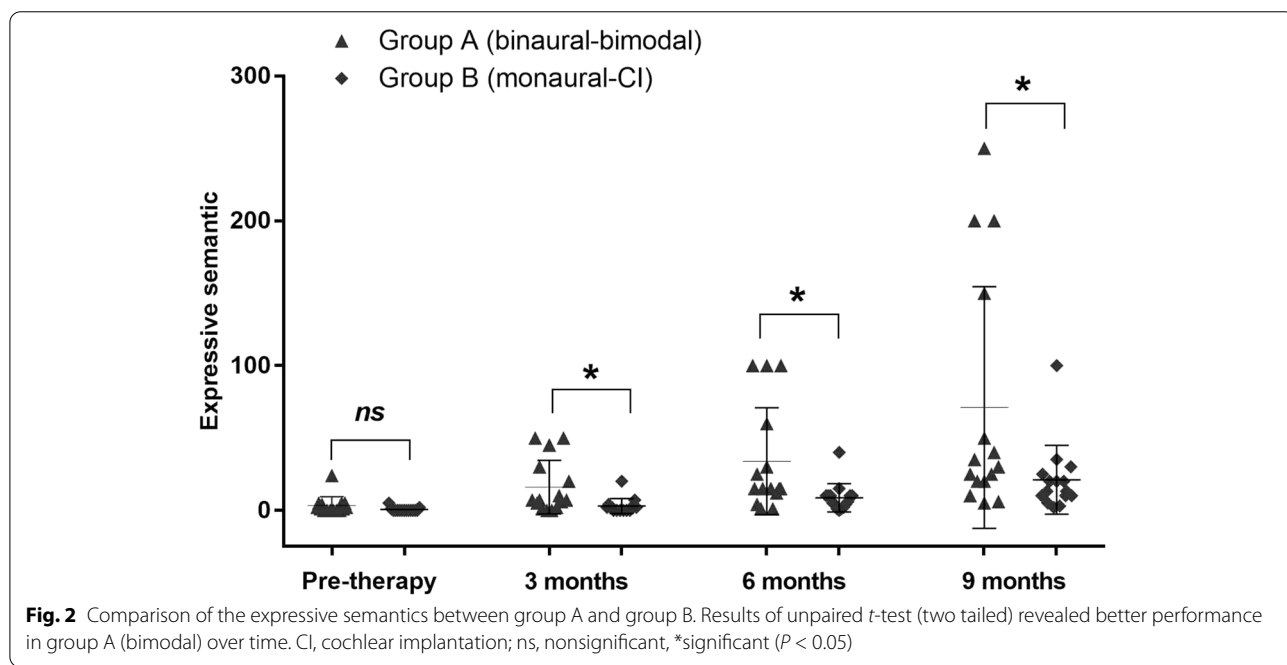
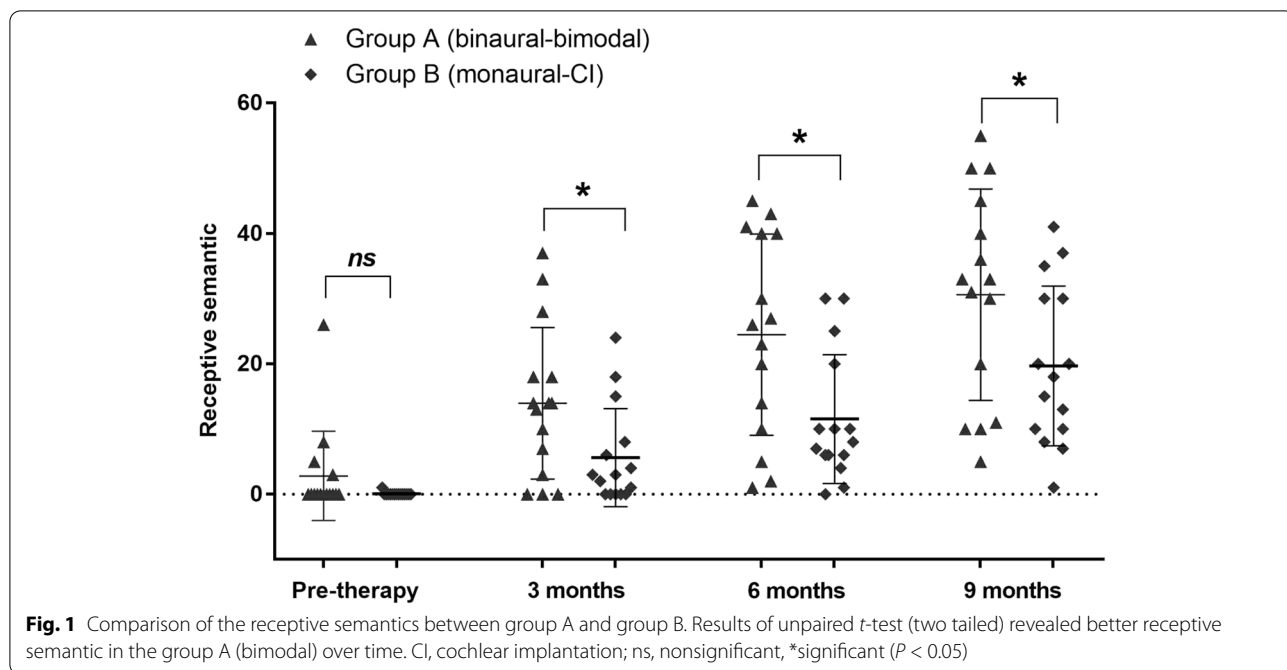
2. Speech intelligibility: There were significant increases of speech intelligibility score over time in both groups ( $P < 0.001$  for each). The Dunn's multiple comparison test for group A revealed significant differences in 3 comparisons: (pre- versus 6 months), (pre- versus 9 months), and (3 months versus 9 months). The highest rank sum difference was 34 for (pre- versus 9 months) followed by 24.5 for pre- versus 6 months. In group B, the Dunn's multiple comparison test revealed significant differences in only 2 comparisons: (pre- versus 9 months) and (3 months versus 9 months) with the highest rank sum differences were 29 and 23, respectively (Table 4).

The unpaired *t*-test was used to compare between the two groups in each time-point (two-tailed *p*-value and confidence interval 95%). The measure of *G* power revealed that effect size is 1.364 and  $DF = 28$ . The means, standard deviations, and *p*-values of the comparison between the 2 groups were shown in Table 5. The improvement of language outcome was significantly better in group A as evidenced by the *t*-test results. Although the receptive and expressive semantics showed no significant difference between the two groups pre-therapy, they revealed significant differences in the time-points 3, 6, and 9 months (Figs. 1 and 2). The receptive semantic in group A was more than that of group B after 3 months ( $P = 0.027$ ). Similarly, group A revealed more receptive semantic than group B after 6 and 9 months with significant differences:  $P = 0.011$  and  $0.047$ , respectively (Fig. 1). Similarly, the expressive semantic in group A was more than that of group B in the 3-, 6-, and 9-month time-points:  $P = 0.013$ ,  $0.016$ , and  $0.034$ , respectively (Fig. 2). The word class score revealed no significant difference

**Table 5** Descriptive statistics and results of unpaired *t*-test for both groups

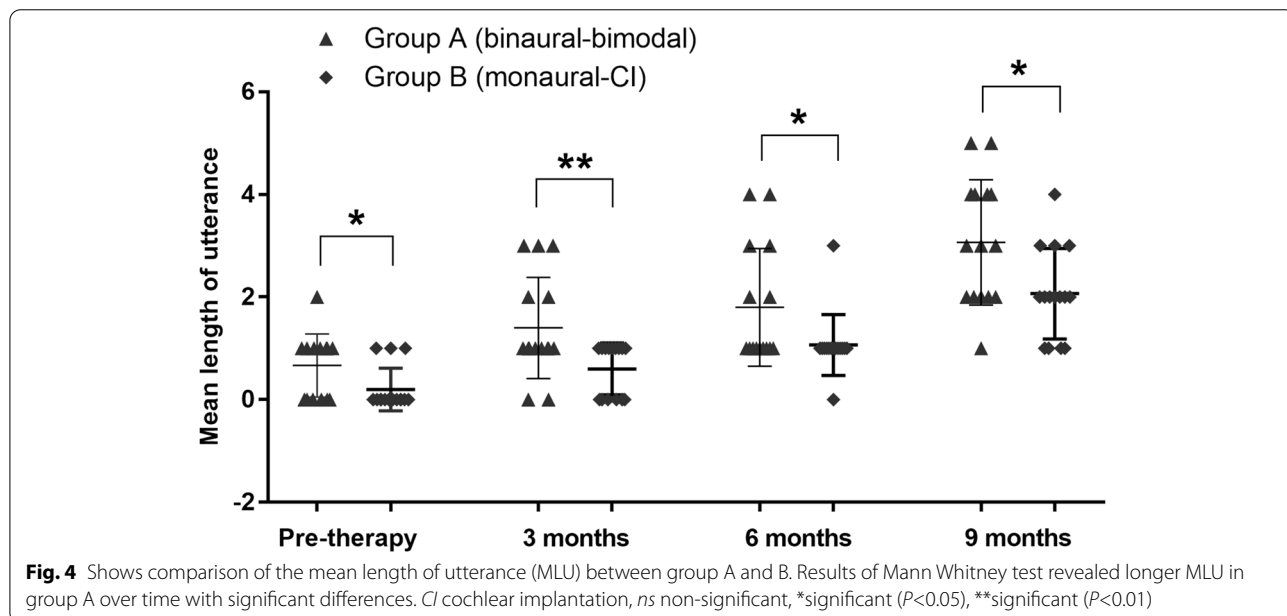
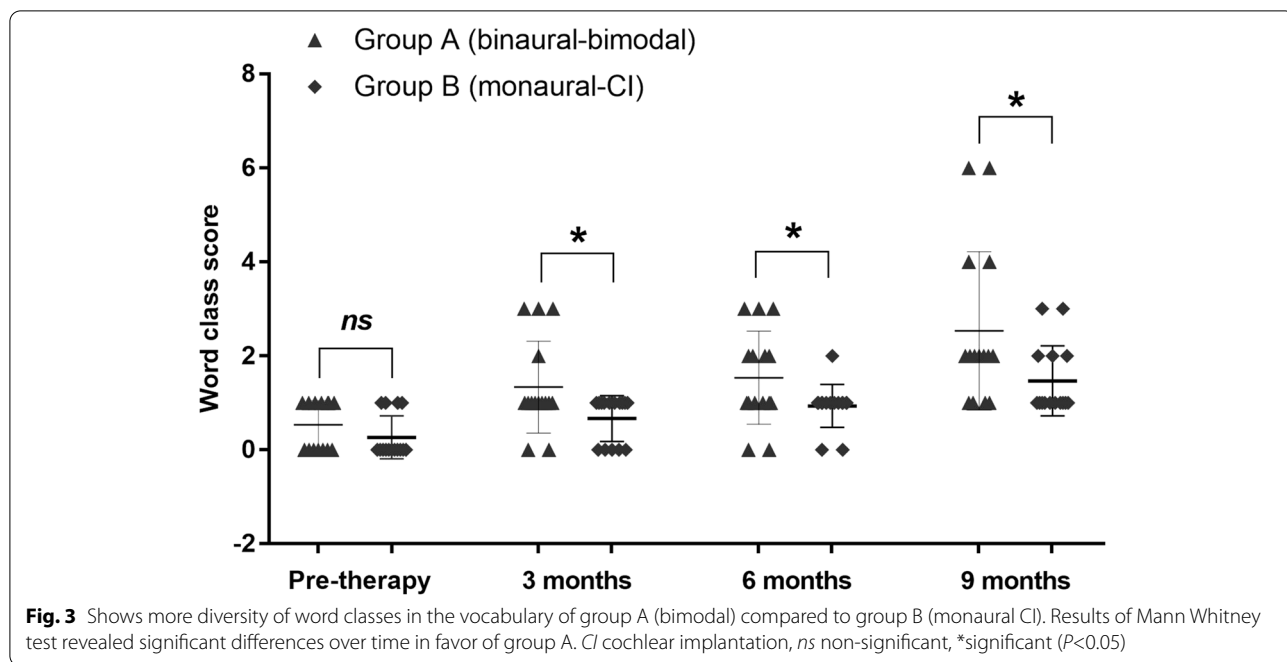
Time-point	Groups	RS		ES		WC		SI		MLU	
		Mean ± SD	<i>P</i>	Mean ± SD	<i>P</i>	Mean ± SD	<i>P</i>	Mean ± SD	<i>P</i>	Mean ± SD	<i>P</i>
Pre-therapy	Group A	2.8 ± 6.85	ns	3.26 ± 6.08	ns	0.53 ± 0.5	ns	0.6 ± 0.74	ns	0.67 ± 0.6	0.02
	Group B	0.067 ± 0.26		0.53 ± 1.36		0.27 ± 0.46		0.2 ± 0.4		0.2 ± 0.4	
3 months	Group A	13.9 ± 11.6	0.027	16 ± 18.5	0.013	1.33 ± 0.97	0.025	1.33 ± 1	0.003	1.4 ± 1	0.009
	Group B	5.6 ± 7.5		2.87 ± 5.11		0.67 ± 0.5		0.47 ± 0.52		0.6 ± 0.5	
6 months	Group A	24.5 ± 15.4	0.011	34 ± 37	0.016	1.53 ± 1	0.042	1.7 ± 0.7	0.006	1.8 ± 1.15	0.036
	Group B	11.5 ± 9.8		8.53 ± 9.75		0.93 ± 0.46		0.87 ± 0.74		1 ± 0.6	
9 months	Group A	30.6 ± 16.2	0.047	71 ± 83.5	0.034	2.53 ± 1.7	0.03	2.13 ± 0.64	0.028	3.07 ± 1.22	0.016
	Group B	19.7 ± 12.3		21 ± 24		1.47 ± 0.74		1.47 ± 0.9		2.07 ± 0.88	

Table 5 shows the means, standard deviation (SD), and *P*-values of the comparisons between language parameters in both groups  
 RS Receptive semantics, ES Expressive semantics, WC Word class score, SI Speech intelligibility score, MLU Mean length of utterance



between the two groups before therapy ( $P = 0.14$ ). Over time, word class revealed significant differences between the two groups in 3-, 6-, and 9-month evaluations in favor of group A:  $P = 0.025, 0.042, \text{ and } 0.03$ , respectively (Fig. 3). The mean length of sentences (MLU) showed significant differences between the two groups before therapy and in 3-, 6-, and 9-month time-points:  $P =$

$0.02, 0.009, 0.036, \text{ and } 0.016$ , respectively (Fig. 4). Speech intelligibility showed no difference between both groups before therapy ( $P = 0.07$ ). The speech intelligibility score increased in both groups; however, this increase was more evident in group A than group B with significant differences in the 3-, 6-, and 9-month time-points:  $P = 0.003, 0.006, \text{ and } 0.028$ , respectively (Fig. 5).



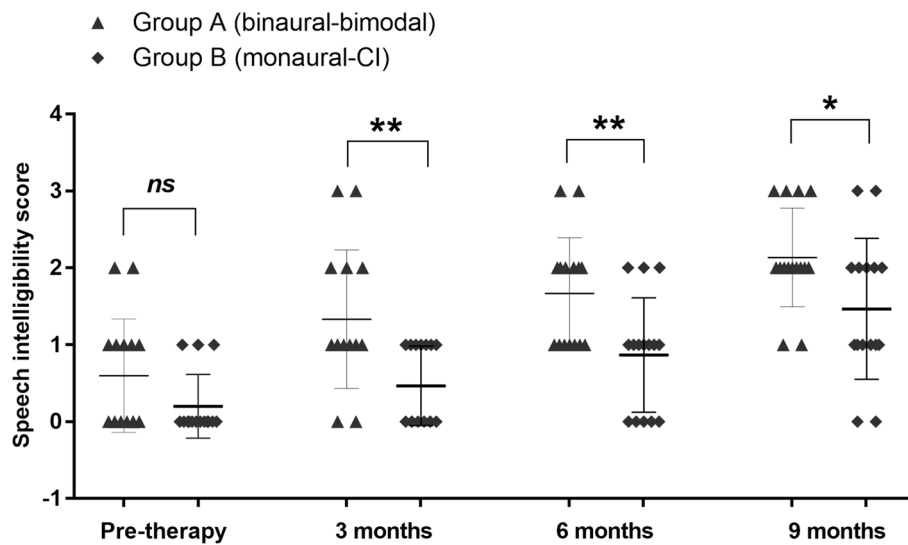
In the current research, 4 subjects from group A did not use a HA soon after CI operation but used it after an average of 3 months. After that period, they showed no response (NR) in the ABR for aided hearing in the contralateral ear, although they had auditory response pre-operatively when they were using bilateral HA. Then, they reused the HA in the contralateral ear regularly for sufficient period (3–5 months). After that, the auditory

response for aided hearing recovered again nearly as it was before (55–65 dBs).

**Discussion**

In the current research, there was no significant difference between the 2 groups pre-therapy. However, group A performed better than group B with significant differences after 3-month, 6-month, and 9-month evaluations as regard receptive and expressive semantics.





**Fig. 5** Showing better speech intelligibility score in group A (bimodal) compared to group B (monaural CI). Results of Mann-Whitney test show better performance over time in group A. CI, cochlear implantation; ns, nonsignificant, \*significant ( $P < 0.05$ ), \*\*significant ( $P < 0.01$ )

The binaural hearing has strong impact on language acquisition in children. Martínez-Cruz et al. [16] found that children with unilateral hearing loss demonstrated lower scores on both receptive and expressive language tests when compared with their peers with binaural typical hearing. Also, bilateral CI users predict faster rates of receptive and expressive language development than unilateral CI when controlling other factors [17]. Binaural hearing has positive impact on language development particularly when achieved early in the life. Robbins [18] stated that the average child who receives a CI in the first 2 years of life learns approximately 1 year of language in 1-year time, while children implanted at 3 or 4 years show slower rate of language growth due to the significant delays that already exist in children's language at the time they receive their implants. Similar result was found in the current research. Our children with bimodal fitting moved from many single words (> 10) to 3-word sentences in 9 months of extensive language therapy, while children with only CI moved from few single words (< 10) to 2-word sentences in the same period. Following language therapy and in spite there was an improvement, our subjects still had a gap compared to their typically developed peers. The cause may be the relatively delayed implantation in our subjects (ages of CI ranged from 18 to 60 months) and short rehabilitation period of study. It has been found that children with any experience with bimodal stimulation had better generative language abilities than children without bimodal experience at all. The explanation made was that the low-frequency signal heard by these children through hearing

aids facilitated their acquisition of language [19]. Also, it has been found that acoustic signal of the contralateral HA provided the largest benefits to speech understanding in bimodal-fit patients [20]. Moreover, a recent study revealed that bimodal participants did report a benefit of bimodal hearing ability in various daily life listening situations [21]. These research [20, 21] were conducted in adult bimodal listeners. However, similar effect may be expected to occur in bimodal-fit children.

There was no significant difference between the 2 groups in the ES before therapy. However, group A performed better than group B after 3 months, 6 months, and 9 months with significant differences. Sarant et al. [17] conducted a study showed that children with bilateral CIs achieved significantly better vocabulary outcomes than did comparable children with unilateral CIs. Also, there was no significant difference in language outcomes between 44 children with bimodal fitting and 49 children with bilateral cochlear implants after controlling for a range of demographic variables [22]. Moreover, it was found that earlier age at cochlear implant activation is associated with better outcomes [22]. Hearing aids may not achieve adequate gain for children with severe-to-profound sensorineural hearing loss. Nonetheless, it provides benefit of the binaural hearing in the bimodal stimulation. This is because HA usually achieve good gain in the low-frequency sounds which may be complementary for the CI in cases of short electrode or incomplete insertion. This is because the hair cells specific for low-frequency sound are located near the apex of the cochlea. This can fill the gap and covers all speech sound

frequency range with positive impact on the language outcomes.

Word class can be considered as a measure for early grammatical competency. Word class showed significant differences between the two groups in 3-month and 6-month evaluations in favor of group A. Furthermore, group A performed much better than group B in 9 months. Group A-acquired varied grammar words over time like pronouns “I and you”; locative words “above, below, behind, in front”; possessives “mine, yours”; questions “what, who, where”; adjectives with their antonyms; and prepositions “in, by, on, from, with” were acquired later in 9-month evaluation. The regular plurals and negation in Arabic are quite different than in English. Regular plurals composed of the nouns plus two sounds merged at its end /at/ instead of /s/ in English. Also, negation in the informal spoken Arabic language composed of the negation word /ma/ followed by verb merged with sound /j/ at its end. In group B, there was less varieties of grammar words (nouns, verbs, and prepositions). The average length of spoken sentence in group A was 3–4 words compared to 2–3 word sentences in group B. Neither of the two groups produced complex sentences. However, children in group A were able to produce larger variety of grammatical words in their simple sentences. Similar finding was reported by Nittrouer and Chapman [19] who compared the numbers of pronouns produced by bimodal-fit and CI only children. They found that the mean (SD) of the numbers of pronouns for bimodal-fit children was 20.79 (13.55), and CI only children was 17.43 (11.28). The numbers of grammatical words acquired by bimodal fit were more than those acquired by CI only children with significant differences [19].

The MLU was increased much more in group A than group B especially in the 9-month evaluation. Only one subject had many single words; the rest of group A had their MLU ranged from 2 to 5 word sentences by the end of study (mean 3.07). In contrast, group B had MLU ranged from 1 to 3 word sentences by the end of study (mean 2.07). Although these improvements, both groups still had delayed language development compared to their peers with matched age. Our participants still need more language therapy for at least 2-year duration. The normal children aged from 4.5 to 5 years can tell long and complex sentences with nearly mature syntactic rules.

Generally speaking, group A performed better than group B at 3 months, 6 months, and 9 months after therapy. Previous researches conducted a study comparing speech intelligibility between 51 children with unilateral cochlear implants and 47 children with typical hearing. They found that typical hearing children achieved ceiling speech intelligibility around the age of 4 years, but

a similar peak was not observed for the children with cochlear implants, who were significantly less intelligible than typical hearing children, when controlling both chronological age and length of auditory experience. They attributed that to the auditory deprivation prior to implantation that appears to be associated with at least some delay even after implantation [23, 24]. This is in consistent with our current research. Moreover, the lower intelligibility score in group B than in group A can be explained by the abnormal cortical auditory configuration in monaural hearing which adversely affect speech comprehension, phonological and word learning, and therefore speech production. Unlike group A, the speech output of group B contains multiple phonological omissions and substitutions. One major factor which affected speech intelligibility in our subjects is speech prosody. Children spoke with deviated intonation and stresses; this was more evident in group B than group A. So, late and unilateral treatment of sensory-neural hearing impairment may be the main predisposing factors for deviated prosodic patterns of speech in the hearing-impaired children. Other variables have been mentioned to affect speech intelligibility in the prelingual CI children including duration of wearing HA, duration of therapy before CI, age of CI, and duration of therapy after CI [25]. Our current research is consistent with the age of CI as those implanted after 3 years are among the poor speech intelligibility children.

In the current study, large variability in the vocabulary size, length of spoken sentences, and general language outcomes were found even within the same group. This can be explained by multiple factors which showed some variability among our subjects. These are the age of CI operation, speech reading ability, and language-stimulating environment at home and outdoors. This included how the parents and caregivers talked to their children and to what extent they followed the family counseling given by the Phoniatrician and practiced the structured speech situations. Generally speaking, faster rates of vocabulary growth and language development were found in children with bimodal fitting in the current research. This finding suggested that the perceptual benefits of bilateral hearing through CI and hearing aid conferred a significant advantage, in terms of language acquisition in those children. Binaural hearing improves speech perception in both quiet and noisy listening conditions and sound localization ability [26]. Also, the binaural hearing reduces listening effort and therefore reduced tiredness and provided a greater ability to concentrate [27]. These perceptual benefits reported for children with binaural stimulation may facilitate a greater ability to access the spoken language of others and to learn from these increased opportunities [28, 29]. There

were 4 children in group A showed response of their aided hearing about 55–65 dBs after they had NR. This may be explained by recovering of aided hearing from the brain neglect following re-aiding of the deprived ear. Further researches with more subjects are needed to confirm this finding. The HA may be complementary to the CI not only for achieving binaural hearing but also for covering speech frequency range. Intraoperatively, the electrode may not reach the apex of the cochlea which contains hair cells specific for low-frequency sounds. On the other hand, the HA usually achieves good gain for low-frequency sound which fills the gap. The Arabic language contains more consonants and fewer vowels than English. However, Arabic and English have closely similar intonation patterns in contour and meaning [30]. We recommend preserving the ear with residual hearing in unilateral CI for aiding unless there is a strong surgical cause. This is to keep that ear for possible HA fitting later on. Also, the regular use of both HA before CI operation and the use of contralateral HA after operation in case of unilateral CI are advisable.

Many children with bilateral sensorineural hearing impairment received unilateral cochlear implant at least for an extended period of time. These children may not continue wearing a hearing aid in the contralateral/non-implanted ear. This results in auditory deprivation which adversely affects the hearing and oral language acquisition. We recommend using a HA in the non-implanted ear (with residual hearing) in unilateral CI children until the second CI become available. Also, such children may continue using bimodal fitting whenever bilateral cochlear implant is not available. Like any research, ours has their own limitations which are small sample size and short period of study. The current research provided preliminary results. Further longitudinal studies with more subjects may be required to generalize our results. Also, we recommend studying the prosodic patterns in bimodal fitting compared to unilateral CI over longer periods.

### Conclusion

Bimodal-fit children showed significantly better language outcomes with longer sentence production and more developed syntactic rules than monaural-CI children. The methods of stimulating the auditory nerve are different between the two modes. However, with intensive auditory training and language therapy, the brain can incorporate and benefit the impulses received from both ears simultaneously in the bimodal-fit children. This achieves auditory skills development in early childhood which improves oral language perception and development in different speaking situations.

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### Authors' contributions

MMH made concept and design and data acquisition, drafted the manuscript, and analyzed and interpreted the patient data regarding the patient information and language evaluations. AAN and AME formulated the concept, interpret results, develop the intellectual content, and critically revise the manuscript. AFS participated in the design of the work, acquisition, and analysis of data and drafted part of the manuscript and develop intellectual content of the manuscript. All authors have agreed to be personally accountable for the author's own contributions and to ensure that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. The authors read and approved the final manuscript.

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### Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

### Declarations

#### Ethics approval and consent to participate

Written informed consent was taken from family of every child to participate in the research. This research was approved by Medical Research Ethics Committee of Faculty of Medicine, Sohag University under IRB Registration number: Soh-Med-22-02-21.

#### Consent for publication

Not applicable

#### Competing interests

The authors declare that they have no competing interests.

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