Value of early intervention for hearing impairment on language and speech acquisition

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Background
It is well known that early diagnosis and intervention for hearing impairment is crucial for normal development of language and speech and for a normal life in the future. This study was carried out on 58 patients suffering from sensory-neural hearing loss. They were divided into four groups:
Group A ($n = 16$)
Group B ($n = 22$)
Group C ($n = 14$)
Group D ($n = 6$).
The first three groups had severe sensory-neural hearing loss and were bilaterally amplified with hearing aids at the time of diagnosis. They were classified according to the age of amplification into group A, which included children amplified before 6 months of age, group B, which included children amplified between 6 and 12 months of age, and group C, comprising children amplified at 12–24 months of age. The last group (group D) included six children with severe to profound sensory-neural hearing loss. This group had undergone unilateral cochlear implantation. Children of this group were implanted at the age of 4 ± 1.2 years. For all children language and speech assessment was performed at school age. The results were compared among all groups.

Conclusion
Hearing intervention at the age of 6 months had the best outcome in terms of language development, even when compared with the group with late cochlear implantation.

Introduction

Speech and language are tools that humans use to communicate with each other. Language comprises a set of rules shared by the individuals who are communicating. Language allows people to exchange their thoughts, ideas, and emotions [1]. Speech is the way that a language can be expressed. Language can also be expressed through nonverbal modes like writing, signs, and gestures. Nonverbal communication is frequently used when people fail to develop verbal communication [1].

It is well known that intact hearing is crucial for normal development of language and speech and for a future normal lifestyle for the patient. Thus, early diagnosis and intervention for hearing impairment leads to less serious impacts [1].

The Joint Committee on Infant Hearing endorses early hearing detection and intervention for infants with hearing loss. The goal of early hearing detection and intervention is to maximize linguistic and communicative competence for children who are hard of hearing or are deaf [2]. It was also reported that early detection and intervention for auditory dysfunction in neonates leads to development of better cognitive functions [3].

Early identification of hearing loss in infants can be traced back to the tireless work of Dr Marion Dawns in the 1960s. The word 'early' was expressed by several researchers as the 'critical period' for primary language acquisition. This period is a certain developmental stage at which auditory signals are received and utilized for prelinguistic activities. Once this period has passed, the effective utilization of these signals gradually declines. Hence, the importance of hearing in the first 3–4 years after birth for normal acquisition of speech and language has long been appreciated [4]. The National Institute of Health (NIH), which is a part of the US Department of Health and Human Services, widely recognized that the critical period for speech and language development is the first 3 years of life [5].

Furthermore, other researchers proposed a critical period under 2 years of age during which access to spoken language is essential for appropriate acquisition of language [6].

NIH indicated that children who are identified with a hearing loss and habilitated early may be able to develop language on par with their peers with normal hearing. If hearing loss is detected in a child, early family-centered intervention is recommended to promote language (speech and/or sign depending on family choice) and cognitive development [1].

Thus, what is the optimal age for amplification that permits a hearing impaired child to be as normal as possible? The other question we tried to answer in this study was whether there was a difference between acoustic stimulation (hearing aids) and electric stimulation [cochlear implantation (CI)] of the auditory nerve?

Patients and methods

This study was conducted on 58 children attending the Audiology and Phoniatric Units, Zagazig University Hospital, during the period from 2006 to 2012. The age range, when first seen, was between 2 and 24 months. Older children were presented with lack of response to sounds or delayed language development. Presence of other affected members in the family contributed to very early presentation of cases. All children were matched with respect to socioeconomic status as much as possible. Study cases were divided into three groups with respect to the age of identification and intervention for hearing loss. Then a fourth group was added, which included six cases with CI who showed poor response for HI. These children had poor functional gain of hearing aid, poor compliance during language therapy sessions, and unsatisfactory response of their parents. Group A was amplified before the age of 6 months, group B was amplified between 6 and 12 months of age, and group C was amplified at age 12–24 months. The fourth group, group D, comprised the last six cases with CI.

Inclusion criteria were:

(1) Severe or severe-to-profound sensory-neural hearing loss as diagnosed by ABR.
(2) Average intelligence quotient (IQ) based on psychometric testing.
(3) Regular use of binaural hearing aids with satisfactory aided response for groups A, B, and C.
(4) Regular use of unilateral CI for group D (4.1 ± 0.6) with satisfactory audiological response.
(5) General language stimulation and regular language and speech therapy for at least 2 years after amplification or CI.

All children were subjected to:

(1) Initial assessment:
  (a) Full history taking, including, prenatal, perinatal, and postnatal history, as well as developmental milestone history and family history.
  (b) Full audiological assessment:
    (1) Behavioral observation audiometry using audiometer Amplaid 922 performed in a sound-treated room.
    (2) Air conduction click evoked auditory brain stem response using Intelligent Hearing System Smart Evoked Potential.
    (3) Transient evoked emission for assessment of outer hair cell integrity and excluding auditory neuropathy using ILO Version 6 (Otodynamics Ltd, UK) [6].
    (4) Distortion product otoacoustic emission to assess lower frequencies using ILO version 6 [6].
  (c) After diagnosis was established, all children were fitted with binaural hearing aids (Widex B32 (Widex, Denmark) and Oticon Sumo (Oticon, Denmark)). Six children (14%) showed poor response for hearing aids after a trial of more than 6 months and they were included in the cochlear implant program. They were unilaterally implanted at a mean age of 4 ± 1.2 years. One child used advanced Bionics Auria (Switzerland) and the other five children used Med El Opus 2 (MED-EL Elektromedizinische Geräte GmbH Headquarters, Innsbruck, Österreich).
  (d) IQ assessment was made to ensure that all children had average mental development. Forty-nine children (84%) had average IQ (94 ± 3.1) and nine children (16%) had above average IQ.
  (e) Neurological and ophthalmologic evaluation was carried out to exclude any other handicap.
  (f) Language stimulation program was started immediately after fitting of the hearing aid or CI and was regularly attended by all children. It included active therapy sessions that aimed at improving cognitive abilities, increasing the size of active vocabularies, increasing the length of sentences, and correction of syntactic and phonologic errors. Language stimulation also included family counseling, which was discussed during follow-up visits.

(2) Follow-up visits: regular visits were performed every 3 months.

(a) Parents were informed about the normal development of language in normal-hearing children.

(b) Parents were informed about activities to encourage speech and language development.

(c) Aided behavioral observation audiometry was used for relatively older children.

(d) Functional gain assessment was applied for older children.

(e) The Child Development Inventory, completed by parents at home, assesses the development of social, self-help, motor, language, letter and number skills, and presence of symptoms and behavioral problems in children between the ages of 15 months and 5 years [7].

All children were followed up regularly until school age, and then a final assessment was made including language and speech assessment. This assessment was used for comparison of results.

Language was assessed using the Standardized Arabic Language Test [8]. This test measures receptive and expressive language skills, giving the total language age in years. Language deficit was expressed as language quotient. It was calculated by dividing language age by the chronological age. Language quotient was used to avoid biased results if language age was used, as children had different chronological ages at the time of assessment.

Speech analysis was performed using a speech assessment protocol, which included analysis of suprasegmental phonology (rate, stress, and tonality), segmental phonology (consonants and vowels), nasal resonance, and general intelligibility of speech, as well as voice (dysphonia). Every item was given a score that ranged from 0 (normal) to 4 (denoting severe abnormality) except for general intelligibility, for which score 4 indicated normal and 0 indicated severely unintelligible speech [9]. Speech scores were analyzed and compared after the age of 3 years when possible. Before this age it is difficult to assess speech.

Statistical analysis

Statistical package for the social sciences, version 17 (SPSS Inc., Chicago, Illinois, USA) was used to analyze the data. The means and SDs for all language and speech scores were calculated. One-way analysis of variance was used to compare more than two means, whereas the independent *t*-test was used to compare two means. *P* values less than or equal to 0.001 indicated highly significant values, whereas *P* values less than 0.05 indicated significant values only and

P values greater than 0.05 indicated nonsignificant values.

Results

The results of assessment of language abilities revealed that group A had the best language quotient score in the study, which was for semantics (93.5 ± 5.6). The worst quotient was in group C, which was for expressive syntax (70.22 ± 6.53). Speech deficits in this study were variable, but the most common findings were as follows: on the suprasegmental level there was slow rate of speech, as well as variable stresses. On the segmental level there were distorted vowels and omitted and substituted consonants (especially fricatives, which were substituted with stops), as well as increased nasal resonance.

The group with the highest nasal resonance was group C (2.1 ± 0.4), whereas the group with the lowest nasal resonance was group A (1.3 ± 0.5). There was also decreased intelligibility of speech. The group with the most intelligible speech was group A (3.4 ± 0.4), whereas the group with the least intelligible speech was group C (2.8 ± 0.6).

Comparison between the three groups with hearing aids with respect to language quotients and speech scores revealed highly significant differences in all parameters except pragmatics and general intelligibility, which showed significant differences. The highest language and speech scores were obtained in group A with gradual decrease in scores in groups B and C (Tables 1 and 2).

Comparison between group A and group D showed better results for group A in all language and speech scores. There were highly significant differences in expressive syntax, stress, vowels, and pitch scores. Significant differences were obtained for receptive syntax, semantics, pragmatics, phonology, total language quotients, general intelligibility, and loudness (Table 3).

Comparison between groups B and D showed some similarity in the results, seen as nonsignificant differences in all language and speech scores, except stress, which showed significant difference, with better results in group B, and pitch, which showed highly significant difference with better scores in group D (Table 4).

Comparison between groups C and D showed some similarities and some differences between results as seen through highly significant differences in expressive syntax, semantics, tonality, and pitch. Significant differences were obtained for resonance and loudness and nonsignificant differences for the remaining scores.

Table 1 Comparison between groups A, B, and C with respect to language quotients and speech scores

Language quotients and speech scores	Mean ± SD			F	P
	Group A (n = 16)	Group B (n = 22)	Group C (n = 14)		
Language quotient					
Receptive syntax	89.1 ± 6.3	80.1 ± 5.5	76.43 ± 7.1	17.2	<0.001**
Expressive syntax	92.8 ± 4.1	79.16 ± 6.3	75.21 ± 5.9	34.961	<0.001**
Semantics	93.5 ± 5.6	82.6 ± 7.3	77.98 ± 6.3	22.9	<0.001**
Pragmatics	83.5 ± 5.7	81.6 ± 4.5	77.43 ± 7.1	4.471	0.016
Prosody	86.1 ± 5.6	74.3 ± 6.2	71 ± 5.7	28.668	<0.001**
Phonology	88.5 ± 5.7	78.32 ± 5.8	75.5 ± 6.7	6.762	0.003**
Total language quotient	89.5 ± 6.3	79.12 ± 5.1	76.7 ± 6.8	20.664	<0.001**
Speech scores					
Rate	0.5 ± 0.1	0.9 ± 0.3	1.1 ± 0.3	21.91	<0.001**
Stress	0.5 ± 0.1	0.8 ± 0.2	0.9 ± 0.2	22.029	<0.001**
Tonality	0.6 ± 0.1	0.9 ± 0.3	1.3 ± 0.2	35.1	<0.001**
Consonants	0.7 ± 0.2	0.9 ± 0.1	1 ± 0.4	6.1	<0.001**
Vowels	0.3 ± 0.1	0.5 ± 0.2	0.8 ± 0.3	21.3	<0.001**
Resonance	1.3 ± 0.5	1.9 ± 0.4	2.1 ± 0.4	22.01	<0.001**
General intelligibility	3.4 ± 0.4	3.1 ± 0.5	2.8 ± 0.6	5.4	0.008*
Pitch	0.6 ± 0.2	0.9 ± 0.3	1.1 ± 0.3	12.9	<0.001**
Loudness	0.5 ± 0.1	0.7 ± 0.2	0.9 ± 0.2	19.4	<0.001**

n, number of cases; *Significant; **Highly significant.

Table 2 Comparison between the groups B and C with respect to language quotients and speech scores

Language quotients and speech scores	Mean ± SD		t	P
	Group B (n = 22)	Group C (n = 14)		
Language quotient				
Receptive syntax	80.1 ± 5.5	76.43 ± 7.1	1.645	0.149
Expressive syntax	79.16 ± 6.2	75.22 ± 5.9	1.907	0.067
Semantics	82.6 ± 7.3	77.98 ± 6.3	2.015	0.056
Pragmatics	81.6 ± 4.5	77.43 ± 7.1	1.961	0.0622
Prosody	74.3 ± 6.2	71 ± 5.7	1.636	0.1098
Phonology	78.32 ± 5.8	75.5 ± 6.7	1.296	0.2056
Total language quotient	79.12 ± 5.1	76.7 ± 6.8	1.199	0.2466
Speech scores				
Rate	0.9 ± 0.3	1.1 ± 0.3	−1.95	0.03026
Stress	0.8 ± 0.2	0.9 ± 0.2	−1.522	0.1408
Tonality	0.9 ± 0.3	1.3 ± 0.2	−4.927	<0.001**
Consonants	0.9 ± 0.1	1 ± 0.4	−0.978	0.348
Vowels	0.5 ± 0.2	0.8 ± 0.3	−3.477	0.001**
Resonance	1.9 ± 0.4	2.1 ± 0.4	−1.522	0.07037
General intelligibility	3.1 ± 0.5	2.8 ± 0.6	1.63	0.1188
Pitch	0.9 ± 0.3	1.1 ± 0.3	−2.029	0.0524
Loudness	0.7 ± 0.2	0.9 ± 0.2	−3.044	0.005*

n, number of cases; *Significant; **Highly significant.

Table 3 Comparison between group A and group D with respect to language quotients and speech scores

Language quotients and speech scores	Mean ± SD		t	P
	Group A (n = 16)	Group D (n = 6)		
Language quotient				
Receptive syntax	89.1 ± 6.3	79.31 ± 6.2	3.26	0.003*
Expressive syntax	92.8 ± 4.1	82.11 ± 4.3	5.38	<0.001**
Semantics	93.5 ± 5.6	84.3 ± 5.3	3.47	0.002*
Pragmatics	83.5 ± 5.7	75.1 ± 4.5	3.23	0.004*
Prosody	86.1 ± 5.6	77 ± 7.2	2.795	0.0198*
Phonology	88.5 ± 5.7	79.5 ± 4.7	3.43	0.002*
Total language quotient	89.5 ± 6.3	80.1 ± 7.1	3.02	0.006*
Speech scores				
Rate	0.5 ± 0.1	0.8 ± 0.3	−2.4	0.045*
Stress	0.5 ± 0.1	0.9 ± 0.2	6.32	<0.001**
Tonality	0.6 ± 0.1	0.9 ± 0.2	−3.513	0.0124
Consonants	0.7 ± 0.2	0.8 ± 0.3	1.57	0.13
Vowels	0.3 ± 0.1	0.6 ± 0.1	6.27	<0.001**
Resonance	1.2 ± 0.4	1.7 ± 0.3	−3.162	0.00419
General intelligibility	3.4 ± 0.4	2.9 ± 0.4	2.61	0.02*
Pitch	0.2 ± 0.1	0.4 ± 0.1	4.18	<0.001**
Loudness	0.4 ± 0.2	0.6 ± 0.1	2.31	0.03*

n, number of cases; *Significant; **Highly significant.

Better scores were noticed to some extent in group D (Table 5).

Discussion

It was noted that detection and intervention of hearing loss at earlier ages leads to more success of habilitation programs compared with late detection and intervention [10].

In this study, significant and highly significant differences were found among groups A, B, and C in all tested language and speech abilities. It was clear that the best results could be obtained in the group with hearing aids fitted before the age of 6 months (group A).

Table 4 Comparison between group B and group D with respect to language quotients and speech scores

Language quotients and speech scores	Mean ± SD		t	P
	Group B (n = 22)	Group D (n = 6)		
Language quotient				
Receptive syntax	80.1 ± 5.5	79.31 ± 6.2	0.3	0.76
Expressive syntax	79.16 ± 6.2	82.11 ± 4.3	−1.33	0.2
Semantics	82.6 ± 7.3	84.3 ± 5.3	−0.63	0.533
Pragmatics	81.6 ± 4.5	75.1 ± 4.5	1.16	0.25
Prosody	74.3 ± 6.2	77 ± 7.2	1.42	0.17
Phonology	78.32 ± 5.8	79.5 ± 4.7	−0.517	0.6096
Total language quotient	97.5 ± 5.1	80.1 ± 7.1	−0.31	0.7708
Speech scores				
Rate	0.9 ± 0.3	0.8 ± 0.3	0.72	0.47
Stress	0.8 ± 0.2	0.9 ± 0.2	−1.086	0.308
Tonality	0.9 ± 0.3	0.9 ± 0.2	0	1
Consonants	0.9 ± 0.1	0.8 ± 0.3	1.63	0.18
Vowels	0.5 ± 0.2	0.6 ± 0.1	1.17	0.25
Resonance	1.9 ± 0.4	1.7 ± 0.3	1.13	0.26
General intelligibility	3.1 ± 0.5	2.9 ± 0.4	2.9	0.38
Pitch	0.9 ± 0.3	0.4 ± 0.1	3.9	<0.001**
Loudness	0.7 ± 0.2	0.6 ± 0.1	1.17	0.25

n, number of cases; *Significant; **Highly significant.

Table 5 Comparison between group C and group D with respect to language quotients and speech scores

Language quotients and speech scores	Mean ± SD		t	P
	Group C (n = 14)	Group D (n = 6)		
Language quotient				
Receptive syntax	76.43 ± 7.1	79.31 ± 6.2	0.86	0.4
Expressive syntax	75.16 ± 6.3	82.11 ± 4.3	−3.12	0.008**
Semantics	72.6 ± 4.2	84.3 ± 5.3	5.29	<0.001**
Pragmatics	77.43 ± 7.1	75.1 ± 4.5	0.979	0.3602
Prosody	71 ± 5.7	77 ± 7.2	1.97	0.07
Phonology	75.5 ± 6.7	79.5 ± 4.7	1.32	0.2
Total language quotient	76.7 ± 6.8	80.1 ± 7.1	0.92	0.36
Speech scores				
Rate	1.1 ± 0.3	0.8 ± 0.3	1.01	0.32
Stress	0.9 ± 0.2	0.9 ± 0.2	0	1
Tonality	1.3 ± 0.2	0.9 ± 0.2	4.09	<0.001**
Consonants	1 ± 0.4	0.8 ± 0.3	1.09	0.29
Vowels	0.8 ± 0.3	0.6 ± 0.1	1.57	0.13
Resonance	2.1 ± 0.4	1.7 ± 0.3	2.18	0.04*
General intelligibility	2.8 ± 0.6	2.9 ± 0.4	0.37	0.71
Pitch	1.1 ± 0.3	0.4 ± 0.1	5.51	<0.001**
Loudness	0.9 ± 0.2	0.6 ± 0.1	3.46	0.003*

n, number of cases; *Significant; **Highly significant.

Similar findings were reported by other studies supported by the NIH. They concluded that detection and intervention for hearing loss before the age of 6 months resulted in significantly better language ability compared with that in children who were identified later [10]. The same observation was made by Hall [11] regardless of the degree of hearing loss.

Bassiouny *et al.* [12] reported that children have the best opportunity to learn language during their first 5 years of life. This may be explained by the theory of the critical period. Critical period was defined as a restricted developmental period during which the nervous system is particularly sensitive to the effects of experience [13]. It is known that the number of neurons in the brain actually decreases throughout development; as neural connections grow and the pathways become more efficient, the supporting structures in the brain increase [14]. The brain grows rapidly for the first 5 years of human development. At the age of 5 years, the human brain is 90% of its total size. Then the brain stops growing gradually until age 20 [15,16]. The critical period can be defined as the initial years of brain development, which is essential for intellectual development. During this period the brain optimizes the overproduction of synapses present at birth. Thus, the neuronal pathways are refined, on the basis of which synapses are active and receiving transmission. It is the phenomenon of 'use it or lose it' [13]. The principles 'use it or lose it' and 'use it and grow it' are based on the principles of plasticity of the brain. The sensory experience, stimulation, and language exposure during this critical period may determine synaptogenesis, myelination, and neuronal connectivity [17].

In contrast, although there was a gradual deterioration in language and speech abilities with delayed age of fitting of hearing aids, there was no significant difference between groups B and C. These results prove that, after 6 months of age, amplification within the first 2 years of life gives almost similar results with respect to language acquisition.

Explanation may involve another fact of relevance in that, as myelination increases, plasticity decreases [17]. Thus, knowledge of myelination milestones may further explain this result. The first myelination is seen as early as in the 16th week of gestation, but only really takes off from the 24th week [18]. It does not reach maturity until 2 years or so. It correlates very closely with developmental milestones [19].

On comparing language and speech abilities between groups A and D we found that there were statistically significant or highly significant differences in all language and speech abilities. This means that fitting of bilateral hearing aids before the age of 6 months can be superior to CI and may lead to better language and speech acquisition.

Surprisingly, language and speech development of children with CI at less than 4 years of age was comparable in groups B and D, as seen through nonsignificant differences in all language and speech scores except stress and pitch. This means that even those with delayed benefit from hearing aids can catch up with their younger peers through cochlear implants. This may be due to the electrical type of stimulation that can still promote better responses compared with auditory type of stimuli at a far younger age. This is consistent with the results of previous studies indicating that children with a unilateral CI performed at levels similar to hearing aid users with severe hearing loss [20].

Furthermore, on comparing groups C and D, we found some similarities and some differences between results, proved by highly significant differences in expressive syntax, semantics, tonality, and pitch. Significant differences were obtained for resonance and loudness, whereas nonsignificant differences were obtained for the remaining scores. Better scores were noticed to some extent in group D. Thus, for older ages electrical stimulation is considered the only solution for better language outcomes.

Finally, on comparing the results of each of the groups fitted with hearing aids with the group fitted with CI we found that CI is the solution for sensory-neural hearing loss only if we miss early intervention that is achievable only through universal hearing screening, which is not conducted routinely in most countries.

Conclusion
Bilateral hearing aid fitting before the age of 6 months can be considered early enough for a hearing impaired child to gain the best results for language and speech acquisition. We can also conclude that early bilateral acoustic stimulation (hearing aid fitting) is better than late unilateral electric stimulation (CI).

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