Does early cochlear implantation promote better reading comprehension skills?

Letizia Guerzoni, PhD[1]*; Patrizia Mancini, MD*[2]*; Maria Nicastri*[2]*, PhD; Enrico Fabrizi, PhD* [3]*; Ilaria Giallini, PhD*[2]*; Domenico Cuda*[1]*, MD.*

[1] Department of Otorhinolaryngology

"Guglielmo da Saliceto" Hospital

Via Cantone del Cristo 40

29121 Piacenza, Italy

[2] Department of Sense Organs, Sapienza University of Rome,

Viale dell'Universita` 31, 00161 Rome, Italy Roma

[3] Department of Economics and Social Sciences, Universita` Cattolica del S. Cuore,

Via Emilia Parmense 84, 29122 Piacenza, Italy

Financial Disclosures: None

Conflict of interest: The authors have no conflicts of interest to disclose

Corresponding author

Letizia Guerzoni, PhD

Department of Otorhinolaryngology

"Guglielmo da Saliceto" Hospital

Via Cantone del Cristo 40

29121 Piacenza, Italy

Guerzoni1@libero.it, +393474411027

Abstract

Objective: to investigate the effect of age at CI activation and to explore the role of other variables such as linguistic skills, stimulation modality and gender on reading comprehension.

Study Design: Prospective observational nonrandomized study.

Methods: 89 children with profound congenital sensorineural hearing loss were included in the study. The mean age at CI activation was 21 months (DS +/- 11; range 7-50). The Italian reading standardized test, “Prove di lettura MT”, was used to assess reading comprehension. The individual raw data MT score were converted into z scores (expected values: means =0 and SD=1). The positive values indicated better performance and negative values indicated worse performance.

Results: Early implanted children achieved significantly better reading comprehension skills, 54 out of 89 children are within 1 SD from the overall mean. 34 children (38.2%) attainted MT z-scores less than 1 SD below the mean.

Children with unilateral CI perform somewhat worse in compared to bilateral CI and bimodal stimulation mode, although the differences were weakly significant from a statistical point of view. A strong and positive correlation (rho 0.69, $p < 0.001$) was found with the lexical and morphosyntactic comprehension (rho 0.70, $p < 0.001$). Not significantly different values were observed for gender and parental education level.

Conclusion: Early cochlear implantation promoted better development of reading skills in children with cochlear implantation.

Key Words: cochlear implant, reading comprehension, linguistic ability.

Level of evidences: outcomes research

Introduction

The pediatric cochlear implantation is a well-defined treatment for severe to profound hearing loss [1–3]. There is a large consensus concerning the benefit derived from early implantation, within 2 years of life, in order to promote a normal development of language and regular school learning, although the linguistic results can be variable [4-7]. In fact, it has been observed on the one hand that early implanted children may develop language delay, from the other hand children implanted later, who developed language delay, may be able to recover the gap at older age [8-10]. This aspect has contributed with other to support controversies concerning the optimal age at implantation. A contribution to clarify disputes can derive from the long-term results in more complex domain such as learning achievements at school. The reading comprehension is an important skill to verify the learning process [11,12]. In fact, it requires good linguistic abilities, i.e. phonological, lexical, grammatical and cognitive, and it could be a good indicator of the benefit of hearing rehabilitation [13-17]. Several studies have analyzed this skill in children with cochlear implant (CI): most of them have shown the positive effect of early CI, although the results are very variable, as evidenced in a recent review. [18-23]. However, it should be considered that the mean age of implantation in these studies ranges from 2 years and 5 months to over 6 years of age [24-29]. This is relatively late considering that in the recent years early implantation has increased and occurs often in the first year of life. Therefore, it is reasonable to expect even better results in this population than those already reported. Furthermore, significative improvement in CI technology has been recently implemented, while of the 21 studies reviewed, only 3 were conducted out in the last 5 years [20]. Therefore, further research is needed in the field of reading skills in children with CI.

The objectives of this study were: 1) to investigate the effect of age at CI activation and 2) to explore the role of other variables such as linguistic skills, stimulation modality and gender on reading comprehension.

Materials and methods

Study Design

This is a prospective observational, nonrandomized, study. All parents signed an informed consent. The study design and subject recruitment were performed according to local ethical committee requirements.

Participants

89 children (50 females and 39 males) with profound congenital sensorineural hearing loss (SNHL), mean age 9,86 (SD=1,98), were included in the study.

The children received CI at the "Guglielmo da Saliceto" Hospital in Piacenza and at the Department of Sense Organs, Sapienza University of Rome. The sample included implanted patients who fulfilled the following criteria: 1) children implanted at pre-school age; 2) inclusion in an auditory-verbal rehabilitation program; 3) bysillabic words speech perception with CI in quiet more than 80% (Italian bysillabic words); 4) normal hearing parents and 5) a monolingual Italian-speaking family. The following exclusion criteria were adopted: 1) evidence of inner ear malformation on high-resolution computed tomography (CT) scan and magnetic resonance imaging (MRI); 2) significant visual or motor problems that may interfere with speech and language development; 3) neurodegenerative disorders and 4) syndromes associated with psychological, development or physical disorders.

The 80% speech recognition in quiet was chosen as the representative result of auditory perception in a wide range of children with CI without associated disorders [30,31]. The etiology of deafness was unknown in 36 subjects; a connexin-26 mutation was found in the other 53 subjects. The mean age at SNHL identification was 14.4 months (SD ±11.3; range 1-44). Mean age at amplification was 15.4 months (SD ±11.2; range 3-44). All children were enrolled in an auditory-verbal rehabilitation program within 2 months from diagnosis. Hearing loss was assessed using Auditory Brainstem Response (ABR, clicks stimuli), which was absent at 90 dB Hearing Level (HL) in all cases, and the visual reinforcement audiometry (VRA) using insert earphones. The pre-implant hearing threshold (measured using pure tones presented at 0.5, 1, 2, and 4 kHz) was 104.9 dB HL (SD ±12.5) on the implanted ear and 105.8 dB HL (SD ±12.6) on the contralateral side. Most children had a symmetrical hearing loss. 43 children received a Nucleus (Cochlear LTD, Sydney, Australia) and 46 an Advanced Bionics (Advanced Bionics AG, Stafa, Switzerland) CIs. The mean age at CI activation was 21 months (SD ±11.4; range 7-50). 17 children wore a hearing aid on the unplanted ear (bimodal stimulation); 45 children wore a unilateral CI. 27 wore bilateral cochlear implant of which 10 had sequential and 17 simultaneous surgery. The mean age at second CI activation was 56.4 months (SD ±28.6; range 27-108). All children had a normal nonverbal intelligence scores as measured by Raven's Coloured Progressive Matrices [32],

All CI children attended a regular school with hearing children, were included in the correct school class by chronological age, and used only oral communication. All tests were conducted using the spoken language. At the time of the evaluation all children were enrolled in mainstream classes: 16 children were in grade two, 27 children in grade three, 9 in grade four, 10 children in grade five, 12 in grade six, 11 children in grade seven and 4 in grade eighth.

Participants' parental education level was measured by the number of years legally required to attain the education levels that they declare. In the Italian formal education system, compulsory education lasts 8 years; 13 years are needed to obtain a high school diploma and 18 years to reach a college degree. Some special schools (Technical or trade degree courses) may require intermediate lengths of time for completion. The 13.5 % of mothers and 18% of fathers had just graduated from middle school; approximately 51, 5 % of mothers and 47 % of fathers had completed high school; and 35 % of parents had graduated from a university. The sociocultural level of the sample was as following: 69% of the children came from families with a middle-high sociocultural level and 31% from families with a low sociocultural level.

Instruments and measures

Reading assessment

To assess the reading comprehension was used the "Prove di Lettura MT" test [33], specifically designed for Italian school-age hearing children (HC). The MT Test has different standardized versions, one for each grade of the Italian mandatory school as well as for high schools. Its validation is based on a large population of children (5700) sampled in different areas of the country. The MT assesses different aspects of children's reading skills: (a) a text comprehension test based on the ability to provide correct answers to a defined set of questions following the reading of a short story; (b) an evaluation of reading speed and (c) the accuracy of reading. In the present study it was used only the text comprehension test. In the reading comprehension task, the children were presented a lecture of a one-page text followed by a multiple-choice task concerning the story content, which differed according to the age level considered. Each test was performed on two stories with very high within-test correlation scores from .63 to .66 as reported by the original MT test. The first story served as training; if the child had understood the task, the second story was administered and it was analyzed for the final score. A version appropriate to each child's school class was presented individually by a speech therapist in a quiet room and lasted at least 30 minutes. The child had to read the text as he/she preferred (silently or aloud). and then to answer questions by selecting the correct answer among four alternatives. The child could go back to the text every time he needed before answering the questions in order to minimize the memory load. The same speech therapist then assigned the scores.

Each correct answer corresponded to 1 point and the final score was the sum of the correct answers for each text. Because of the sample included children from different grades, individual raw data were converted into z scores on the basis of normative data. The z-score data allowed us to evaluate the degree of impairment with respect to age-matched reference data (expected values: means =0 and

SD=1). The positive values indicated better performance and negative values indicated worse performance.

Linguistic assessments

Lexical comprehension was assessed using the Italian version [32], of Peabody Picture Vocabulary Test (PPVT) [34].

This instrument measures the receptive vocabulary of children. It contains 175 black and white stimulus items, displaying 4 pictures per page, which increase in difficulty. The examiner calls out a word, and then the examinee responds by pointing to the picture they think corresponds to the word the examinee has given. The raw score is calculated by subtracting the number of errors from the highest number in the examinee's ceiling set. Test retest reliability and internal consistency were respectively of .93 and .94. The normal PPVT standardized scores range between 85 and 115.The present sample had a mean receptive vocabulary comprehension of 82.3 (SD ±12.9; range 65-110). Morphosyntactic comprehension assessment was undertaken using the Italian version of the Test for Reception of Grammar (TROG)-2 [35]. The TROG-2 is a fully revised and re-standardized version of the widely used TROG, originally developed to investigate morpho-syntactic comprehension skills in children. The TROG-2 consists of 20 blocks, each testing a specific grammatical construction, having an increasing order of difficulty. Each block contains four test items and to pass the block the child need to respond correctly to all of them. Each test stimulus is presented in a four-picture, multiple-choice format with lexical and grammatical foils. For each item, the examiner read a sentence that referred to one of four drawings, and the participant’s task was to point to the one drawing that corresponded to the meaning of the sentence. The score is calculated as total number of blocks passed. Split-half reliability and internal consistency were respectively of .88 e .90.

Also in this case results are referred in terms of standard normalized scores: Authors consider score <1 standard deviation from mean as pathologic and this is indicated into the test's manual as a percentile ≤16°.

Statystical analysis

In descriptive analysis values were expressed as median (min-max) and average (SD) values where appropriate. The bivariate relationships between MT z-scores and other variables is explored by means of the correlation coefficient (Pearson's when the normality assumption cannot be rejected for variables in question, Spearman's otherwise). Comparative analysis between groups of children implanted below/above age 24 months was performed with a T-test and a Wilcoxon signed-rank test with an alpha level = 0.01, based on normal distribution of data verified at the Shapiro-Wilk test. The joint effect of independent variables on the MT z-scores is assessed by means of a linear regression model. P values less than .05 (2-sided) were considered as significant. Analyses were carried out using the Statistical Package for Social Sciences, version 250 (SPSS Inc, Chicago, Illinois).

Results

The sample is characterized by an average MT z-score of 0.04 (SD ±1.05). 54 out of 89 children are within 1 SD from the overall mean. 34 children (38.2%) attainted MT z-scores less than 1 SD below the mean, of these 18 attended the middle school and 16 the elementary school.

The relationship between the MT z-scores and age at cochlear implantation is displayed in Figure 1. Negative correlation is apparent from the picture (Spearman rho equals -0.64, p-value <.001); out of the 27 children implanted at 24 months of live or older only 4 achieved positive MT z-scores, and only 1 is above the 1 SD threshold.

A boxplot comparing the MT z-scores for the two groups identified by 'mono' and 'bilateral' (bilateral or 'bimodal') stimulation modality is displayed in Figure 2. Children with unilateral CI perform somewhat worse in compared to bilateral CI and bimodal stimulation mode, although the differences were weakly significant from a statistical point of view; to assess this we consider both a t-test (p-value 0.04) and Wilkoxon test (p-value 0.04), as the null hypothesis of normality of the MT z-scores was set at p=0.01 using the Shapiro-Wilk test.

Concerning correlations between MT z-score and language tests, a Spearman correlation was adopted because of the failure of the normality test. A strong and positive correlation was found with the PPVT (rho 0.69, p <0.001) and the TROG2 score (rho 0.70, p <0.001).

The joint relationship between the MT z-scores, the age at CI, stimulation modality, gender and level of parental education were studied using a multiple linear regression model. Results are reported in Table 1. In line with expectations, the coefficient associated with age at the CI is negative and statistically significant, while the null hypothesis cannot be rejected for the other three variables.

Discussion

The main purpose of the present study was to investigate the effect of age at CI on reading comprehension abilities in school-age children. The Italian reading test "Prove di lettura MT " was used to assess the reading comprehension of 89 children with profound congenital SNHL. The z-score data allowed us to evaluate the degree of impairment with respect to age-matched reference data (expected values: means =0 and SD=1). The positive values indicated better performance and negative values indicated worse performance. The results showed that the effect of age at implantation was very significant on reading comprehension skills. In fact, early implanted children achieved better reading comprehension than children implanted later. In particular out of the 27 children implanted at 24 months of live or older only 4 achieved positive MT z-scores, and only 1 is above the 1 SD threshold. The second aim of the study was to explore the role of other variables such as linguistic skills, stimulation modality and gender on reading comprehension. Language abilities were assessed in two aspects: lexical and morphosyntactic comprehension.

Lexical comprehension was assessed using the Italian version of Peabody Picture Vocabulary Test (PPVT), while morphosyntactic comprehension was analyzed with the Italian version of the Test for Reception of Grammar (TROG)-2. The results showed significant positive correlation (p-value <0.001) of both PPVT and TROG2 with the MT z-score. Text comprehension is a complex process that involves different abilities, i.e. phonological, lexical, grammatical and cognitive [36-38]. For example, in order to understand a text a child must be able to decode the words on the page, to understand the relationship between them, and finally to build a coherent and meaningful representation of the text [39-41]. The positive correlation that has been found in this study between language skills and reading comprehension is in agreement with this. Therefore, different linguistic skills, strongly influenced by auditory skills, are required to perform this process successfully [42-44]. If there is a delay in the access to adequate treatment of deafness, children with profound SNHL might experience a language delay and this in turn might undermine their academic success [16,17]. The early diagnosis resulting from universal neonatal auditory screening and the advent of CI technology have improved the audiological rehabilitative scenario. The timely access to acoustic speech cues could reduce these unfavorable academic outcomes. There is a good level of evidence about the positive effects that an early CI has on language development [1-4]. Because of the close relationship between linguistic and scholastic abilities it can also be hypothesized a positive effect of early CI on reading comprehension abilities. The results of the present study agree with the evidence of the literature in highlighting the effect of age at CI on reading skills [21].

In the present study, the level of parental education was not significantly associated with the results of reading comprehension. Recent research has shown that the level of parental education can be considered an independent variable that influences the linguistic development of children with IC. Early diagnosis and intervention, together with the mother's high level of education, have a positive impact on the linguistic outcomes of children with CI [Language Outcomes Improved Through Early Hearing Detection and Earlier Cochlear Implantation. Yoshinaga-Itano C, Sedey AL, Wiggin M, Mason CA. Otol Neurotol. 2018 Dec;39(10):1256-1263]. The absence of such a significant association in the present study could be due to the homogeneity of the educational level of parents, in which over 80% of fathers and mothers had a medium-high level of education.

The other variables analyzed were the stimulation modality and gender. 17 children used a hearing aid in the non-implanted ear (bimodal stimulation); 45 children wore a one-sided CI. 27 used a bilateral cochlear implant (10 sequential and 17 simultaneous). Children with unilateral CI had worse performance than those using bilateral CI or bimodal stimulation although the differences were weakly significant from a statistical point of view. These results are novel as there are no other findings in literature focusing on reading skills and stimulation modality. Nevertheless, the present findings are in line with studies showing the benefits of bilateral CI and bimodal stimulation on different hearing abilities such as localization, speech perception in noise and quality of listening [45-48]. Bilateral stimulation improves, in fact, the ability of localization and verbal perception in noise due to the positive effects of binaural redundancy, binaural summation and the shadow effect of the head [49-50]. It is possible to suppose that children with unilateral CI had worse reading comprehension ability also due to the presence of the difficult listening conditions in the classrooms. The benefits of bilateral and bimodal stimulation on verbal perception could therefore explain differences in sample performance.

In analyzing the results related to the gender variable, not significantly different values were observed for males and females. We find few studies that analyzed the variable of gender on reading comprehension abilities in implanted children. Geers for example, found that the girls scored higher than boys on reading skills in primary school [21]. However, it should be noted that the mean age of implantation in this study is much higher (by 5,5 years of age) than those of our sample (21 months). It is therefore reasonable to think that early implantation has a major weight on this result.

Conclusion

Early cochlear implantation promoted better development of reading skills in children with cochlear implantation. Children with unilateral CI perform somewhat worse in compared to bilateral CI and bimodal stimulation mode, although the differences were weakly significant from a statistical point of view. A strong and positive correlation (rho 0.69, $p < 0.001$) was found with the lexical and morphosyntactic comprehension (rho 0.70, $p < 0.001$). Not significantly different values were observed for males and females.

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Caption 1: The relationship between age at CI (in months) and MT (Prove di Lettura) z-score. The correlation is negative (Spearman rho equals -0.64, p-value <.001).

Caption 2: Boxplot comparing the MT (Prove di Lettura) z-scores for the two groups identified by ‘mono’ and ‘bilateral’ (bilateral or ‘bimodal’) stimulation modality. Notches define 95% confidence intervals are around the medians.